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THE MARINE TERTIARY OF THE WEST COAST OF THE UNITED STATES: ITS SEQUENCE, PALEOGEOGRAPHY, AND THE PROBLEMS OF CORRELATION[1]

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INTRODUCTION

Considerable work has been done on the marine Tertiary deposits of the West Coast during the past ten years, and some of the discoveries that have been made have greatly modified many of our previous conceptions. The purpose of this paper is to review some of the most salient facts concerning the stratigraphic divisions, paleogeography, and correlation of these horizons in order to give the reader some idea of the present status of this knowledge.

The paper includes a correlation table of the marine West Coast Tertiary. The construction of such a table is a very difficult task, and it will undoubtedly be a good many years before a table can be made which will be satisfactory to everyone working in this field. None of the West Coast Tertiary horizons has been thoroughly studied: there is a notable lack of detailed mapping, and most of the faunas have been inadequately monographed. The West Coast Tertiary still offers some of the most important problems for stratigraphic and paleontological research in the United States, and if the reader can obtain from this paper some

[1] Read before Geological Society of America, December, 1920.

idea of the problems involved, the task will have been well worth while.

There are several factors, aside from the lack of a sufficient number of trained workers, that have hindered the progress of correlation of West Coast horizons. These factors may be considered under the following headings: (1) temperature differentiation (2) geographical isolation, and (3) poor preservation.

1. It is well known that the marine faunas living on the Pacific Coast can be separated into distinct faunal and geographical provinces. In this respect the West Coast of North America is typical of the whole Pacific border. For example, the fauna found off the coast of Panama is very different from that living along the coast of southern California, and the latter has very little in common with that off the coast of Alaska, while faunas from some of the intermediate areas are almost equally distinct.[1] It is generally recognized that Pleistocene and Recent times mark one of the maximum periods of emergence of all the continents. While this is not true in so great a measure of all the periods of the Tertiary, it is well known that the North American continent was submerged only on its borders, and that during a large part of this time the Pacific and Atlantic oceans were disconnected. The study of the Tertiary faunas along the coast discloses marked evidences of temperature differentiation; the faunas of the north having a more boreal aspect than those of the south.[2] This differentiation was most exterme in the Pliocene and Upper Miocene, and it is undoubtedly because of this that there has been so much confusion in the past in the correlation of the deposits from various sections along the coast now referred to those horizons. There is good evidence of temperature differentiation during the Oligocene and Middle Miocene, and what is more interesting is that accumulated evidence seems to show that this differentiation of the faunas had its effects even as far back as Eocene times.

[1] W. D. Dall, *Summary of the Marne Shellbearing Mollusks of the Northwest Coast of America, Bulletin 112, United States Natural Museum* (1921), pp. 1–213.

[2] J. P. Smith, "Climatic Relations of the Tertiary and Quaternary Faunas of the California Region," *Proc. Cal. Acad. Sci.*, Fourth Series, Vol. IX (1919), No. 4, pp. 123–73.

2. The second factor, that of geographical isolation, was very probably an important one, and if so was the result of numerous partially isolated local basins of deposition. The sediments of the Tertiary were for the most part laid down in geosynclinal troughs which paralleled the present Coast ranges. The number and position of these troughs has varied through the different periods and epochs of deposition. There was therefore a condition similar to that which existed in the Appalachian geosyncline during the Paleozoic. Great thicknesses of clastic sediments, in aggregate exceeding 40,000 feet, were deposited on the West Coast during Tertiary time. These Tertiary basins existed either as large embayments or long inland seas, some of the latter of which were comparable in size to the Mediterranean and were probably nearly as well separated from the main ocean basin. These conditions produced marked local environments, with corresponding local changes in the faunas. It is very probable that the faunas in each basin derived certain peculiar characteristics due to isolation alone.

3. Still another factor that has brought about difficulties in correlation in the West Coast Tertiary has been the rather general poor preservation of the fossil material. The Tertiary beds have been extensively folded and tilted, and this deformation has resulted in the leaching of the original material of the shells, especially in the sandstones and shales. Intensive collecting will in time remedy this difficulty as well as bring to our knowledge a larger number of localities where the fossils are in a better state of preservation.

In presenting a correlation table of this kind, one of the first things that will be asked is the author's point of view in attacking the problems. The point of view accepted is that diastrophism is the fundamental basis for differentiating geologic divisions. In other words, the divisions recognized in this paper have been made on the basis of stratigraphic breaks which are believed to be more than local. It is important to note that every stratigraphic unit thus recognized is also represented by a distinctive fauna.

The paleogeographic maps presented in this paper are not accurate in detail and will undoubtedly be modified by future work. The present knowledge of the geology of the Coast ranges

does not enable one to show the exact location of the shore lines of all the seas that have occupied this general area. However, it is believed that the plates show the approximate distribution of the seas and will give the reader some conception of the location of the most important land masses, the degree of isolation of the basins, and the present known extent of the Tertiary horizons in California.

TERTIARY DIVISIONS

There are at least five major divisions of the Tertiary of the West Coast which in the writer's estimation might be recognized as representing true periods. Each one of these five major divisions is composed of more than one epoch of deposition. Each epoch is represented by distinct faunas which lived in distinct seas. The deposits belonging to each of the major divisions will be referred to as a "series"; thus, the Eocene, Oligocene, Lower-Middle Miocene, Upper Miocene, and Pliocene series. To the deposits of each epoch of deposition the term "group" has been applied. The term "formation" is reserved for the lithologic member within the group.

EOCENE

During the Eocene period of the West Coast there were at least three epochs of deposition, as indicated in the correlation table, and there is a suggestion that there were four and possibly five. At the present time, however, only three distinct stratigraphic divisions have been definitely separated. These are the Martinez (Lower Eocene), Meganos (Middle Eocene), and the Tejon (Upper Eocene). Crustal movements of considerable magnitude separated these epochs. In the region of Mount Diablo, middle California, there is a difference in dip and strike between the Martinez and Meganos groups. Over large areas along the coast where beds of the Meganos and Tejon deposits occur in contact, there is an angular unconformity separating the two. The marine faunas of these three divisions of the Eocene differ greatly from each other, further substantiating the stratigraphic evidence of marked

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hiatuses.[1] Thus, on the West Coast, the Eocene period may be definitely stated to be made up of at least three epochs of deposition and should be recognized as a true period rather than as an epoch.

Correlation of Eocene deposits.—The evidence for the correlation of the West Coast marine Eocene with that of the Gulf and East Coast provinces and through them with Europe is based upon the identity of species or the presence of closely related forms common to the two regions. The evidence appears to be much better for the correlation of the Meganos and the Tejon (Middle and Upper Eocene) than for the Lower or Martinez group. There can be little doubt but that during those epochs of time there was a direct connection between the Gulf of Mexico and the Pacific Ocean.

Climate.—The climate during the Eocene of the West Coast was subtropical or possibly warm temperate rather than tropical. The arkosic character of the Meganos deposits, a character very general on the West Coast, strongly suggests that we are dealing with deposits which were derived from an arid coast, while Tejon sandstones, at most localities in California, are composed almost entirely of pure quartz grains, indicating humid climatic conditions at that time.[2]

(Fig. 1.) *Paleogeography.*—As indicated by the paleogeographic maps, the deposits of the Martinez group (Lower Eocene, Fig. 2) were laid down in much more limited basins than those of the Meganos and Tejon groups. Apparently there were at least four separate basins in California, the connections between which were indirect. It seems very probable that when the faunas obtained from these four areas have been more fully described, we shall find that the geographical factor has caused considerable difference between them.

[1] R. E. Dickerson, "Fauna of the Martinez Eocene of California," *Bull. Dept. Geol., Univ. Cal.*, Vol. VIII (1914), No. 6, pp. 61–180. B. L. Clark, "The Meganos Group, a Newly Recognized Division in the Eocene of California," *Bull. Geol. Soc. Am.*, Vol. XXVIII (1918), pp. 218–96; "Stratigraphy and Faunal Relationships of the Meganos Group, Middle Eocene of California," *Jour. Geol.*, Vol. XXIX (1921), No. 2, pp. 125–65.

[2] R. E. Dickerson, "Climatic Zones of Martinez Eocene Time," *Proc. Cal. Acad. Sci.*, Fourth Series, Vol. VII (1917), No. 7, pp. 193–96.

The Meganos and the Tejon seas (Figs. 3 and 4) were somewhat similar in outline. In middle California the deposits of these epochs were laid down in a great trough of which the present Great Valley of California is a remnant. The Meganos sea was the wider of the two Eocene seas that occupied this depression

FIG. 1.—A key map showing the general distribution of positive and negative areas in California during the Tertiary. Of all the positive areas outlined, No. 6, the Santa Monica Mountain area, is the most problematical. (1) Sierra Nevada area; (2) Klamath Mountain area; (3) Coast Range area; (4) Tehachapi Peninsula; (5) Sierra Madre, San Bernardino, San Jacinto Mountain area; (6) Santa Monica Mountain area.

and was connected with an east and west trough in southern California in the region of the present Santa Ynez Mountains. These two general areas of deposition existed throughout the Tertiary. They were bordered by areas or zones of uplift which have also been more or less permanent. East of the great north and south trough was the Sierra Nevada block which dates back to the Upper

Jurassic. To the west there was a positive area covering the present western side of the Coast ranges of middle California. Apparently throughout the entire Eocene period this area to the west was a positive block; the absence of either continental or marine deposits in this area is the chief basis for the conclusion.

FIG. 2.—Martinez (Lower Eocene)

The smaller positive and negative areas which existed during the Oligocene, Miocene, and Pliocene in this western area were not differentiated during the Eocene.

One of the most permanent positive areas of the Tertiary was that which existed in the region now occupied by the Tehachapi and San Emigdio Mountains (Fig. 1). This area formed the east–west peninsula which separated the northern from the southern basins. The extent of this peninsula varied considerably during the different epochs of deposition. The area now covered by the

Santa Monica Mountains was apparently part of an early positive block bordering the east–west trough mentioned above. To the north of this trough the region now occupied by the Santa Ynez Mountains constituted the westward extension of the old Tehachapi peninsula.

FIG. 3.—Meganos (Middle Eocene)

Some of these old positive areas were so persistent throughout the Tertiary time that they might well be given names, following, on a smaller scale, the example of Schuchert in his *Paleogeography of North America*. Certain of these positive and negative areas have been persistent throughout all Tertiary time, while others were formed at a later date. Also, it is worthy of note that the old positive and negative areas had the same trend as the present mountain ranges.

OLIGOCENE

Accumulated evidence appears to show that there were at least two distinct epochs of deposition on the West Coast during the Oligocene. The two epochs are represented by the Molopophorus lincolnensis and Acila gettysburgensis zones of Dr. C. E. Weaver. They

FIG. 4.—Tejon (Upper Eocene)

will be referred to as the Lincoln and San Lorenzo.[1] Recent field work of the writer has shown fairly conclusively that there were at least two distinct epochs of deposition in Oregon and Washington. He believes that this will prove to be the case in California when more detailed work on the stratigraphy of the Oligocene over wider areas has been completed. It is certain that the two faunas first

[1] C. E. Weaver, "Tertiary Formations of Western Washington," *Wash. Geol. Surv., Bull. 13* (1916), pp. 1–21; "Preliminary Note on the Paleontology of Western Washington," *Wash. Geol. Surv. Bull., 15* (1912), pp. 1–80; "Tertiary Faunal Horizons of Western Washington," *Pub. Univ. Wash.*, Vol. I (1916), No. 1, pp. 1–67.

differentiated in Washington are also represented in the same sequence in California, and tentatively we may consider the Oligocene series as being made up of two distinct parts, referred to in the correlation table as the San Lorenzo series.

The aggregate thickness of the marine beds of the Upper and Lower Oligocene of the West Coast exceeds 10,000 feet. A large part of these sediments consists of shales and shaly sandstones.

Correlation.—The evidence for the correlation of the West Coast marine Oligocene deposits is indirect. No molluscan species or even apparently related forms have been recognized as common to the Oligocene of the West Coast and the Gulf province. The faunal evidence at hand seems to show that after the close of the Tejon epoch (Upper Eocene) there was no direct connection between the Atlantic and the Pacific Coast basins.

Dr. Ralph Arnold was the first to announce the presence of Oligocene in California. The type section of the San Lorenzo is in the Santa Cruz Mountains of the Santa Cruz Quadrangle, California. Dr. Arnold concluded that this formation is of Oligocene age because of its stratigraphic position between beds generally recognized as belonging to the Upper Eocene and Lower Miocene (Vaqueros) age. He observed that the fauna of the San Lorenzo appeared to have both Eocene and Miocene affinities.[1] Later studies of the faunas of the Lincoln and San Lorenzo horizons have borne out Arnold's original conclusions.[2] At the time Arnold did his work the Lincoln horizon had not been differentiated. The fauna of this horizon shows a much closer relationship to that of the Tejon (Upper Eocene) than to that of the Lower Miocene, while the fauna of the San Lorenzo horizon, equivalent to Weaver's Acila gettysburgensis zone, has a Miocene aspect, a fairly large number of the genera and species being common to the two.

[1] R. Arnold, "Tertiary and Quaternary Pectens of California," *U.S. Geol. Surv., Prof. Paper 47* (1906). J. C. Branner, F. G. Newsom, and R. Arnold, *U.S. Geol. Surv., Folio 163*, Santa Cruz Folio.

[2] B. L. Clark, "Occurrence of Oligocene in the Contra Costa Hills of Middle California," *Bull. Dept. Geol., Univ. Cal.*, Vol. IX (1915), No. 2, pp. 9–21; "San Lorenzo Series of Middle California," *Bull. Dept. Geol., Univ. Cal.*, Vol. XI (1918), No. 2, pp. 45–234. B. L. Clark and R. Arnold, "Marine Oligocene of the West Coast of North America," *Bull. Geol. Soc. Amer.*, Vol. XXIX (1918), pp. 297–308.

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Climate.—The temperature conditions during the Oligocene time were fairly uniform along the West Coast as far north as Alaska. The waters of the Lower Oligocene, judging from the molluscan fauna, were subtropical to warm-temperate, while those of the Upper Oligocene sea were more temperate.[1] Thus the fauna of the San Lorenzo horizon (Upper Oligocene) is more closely related to that living off the coast of California, Oregon, and Washington at the present time than it is to that of the Lincoln.

Paleogeography.—The distribution of the Lower Oligocene deposits (the Lincoln horizon) (Fig. 5) corresponds closely to that of the Tejon (Upper Eocene). In California there was a long inland trough corresponding closely to, though somewhat wider than, the present Great Valley of California. The presence of great thicknesses of organic shales of the Kreyenhagen formation, from which the oil of the Coalinga field is derived, indicates that the deepest portion of the Lower Oligocene trough was along the western border of the present San Joaquin Valley.[2]

The distribution of the Upper Oligocene (San Lorenzo) is very different from that of the Lower Oligocene. In California there were two limited basins of deposition, one in middle California in the vicinity of San Francisco, and one in the region of the southern end of the San Joaquin Valley.

A fauna referred to the Oligocene which may be Upper Eocene.—The fauna of the Tejon (Upper Eocene) of the West Coast, as has already been stated, can probably be correlated with the upper Claiborne horizon of the Eocene of the Gulf province, but whether or not there is a fauna on the West Coast that is equivalent to the Jackson horizon of that province can only be proved by further detailed study.

The possibility of referring the Molopophorus lincolnensis zone, now considered Lower Oligocene, to the Jackson stage has been considered. Dr. C. E. Weaver has listed a number of species

[1] R. E. Dickerson, "Climate and Its Influence upon the Oligocene Faunas of the Pacific Coast," *Proc. Cal. Acad. Sci.*, Fourth Series, Vol. VII (1917), No. 6, pp. 157–92.

[2] R. W. Anderson and R. W. Pack, "Geology and Oil Resources of the West Border of the San Joaquin Valley North of Coalinga, California," *U.S. Geol. Surv. Bull. 603* (1915), pp. 74–78.

in the former horizon that are also found in the Tejon and the generic assemblages are notably similar. The Molopophorus lincolnensis zone, however, shows a closer relationship to the Acila gettysburgensis zone (Upper Oligocene) than to the Tejon, and subsequent work on the fauna of the Molopophorus lincolnensis

FIG. 5.—Lower Oligocene

zone has shown that there are fewer species common to the Tejon than Dr. Weaver supposed.[1]

There is still another fauna which may represent an Eocene stage higher than the Tejon. During the year 1912 a collection was made by Mr. F. M. Anderson and Mr. Bruce Martin, at that time curator and assistant curator in the department of paleontology of the California Academy of Sciences, from the Greise Ranch

[1] C. E. Weaver, "Preliminary Report on the Tertiary Paleontology of Western Washington," *Wash. Geol. Surv., Bull. 15* (1912), p. 16; "Tertiary Formations of Western Washington," *Wash. Geol. Surv., Bull. 13* (1916), p. 167.

near the town of Vader in southern Washington. This collection came from beds unconformable on the Tejon, and below strata containing a typical Molopophorus lincolnensis fauna. The fauna was described by Dr. R. E. Dickerson and consisted of forty-eight species, of which thirty-six were considered new and thirteen were determined as common to the Molopophorus fauna.[1] The writer has had the opportunity of making larger collections from the Greise Ranch locality, and with Dr. G. D. Hanna, present curator of the department of paleontology of the California Academy of Sciences, has re-worked the fauna listed and described by Dr. Dickerson. The results of this work show quite conclusively that there is very little, if anything, in common between this fauna and that of the Molopophorus lincolnensis zone. The fauna at the present time consists of about seventy-five species and is very distinct from any other known fauna on the Pacific Coast. None of these species have been definitely determined as common to either the Tejon or the Molopophorus lincolnensis zone, and the stratigraphic position of the horizon renders it possible that these beds are equivalent to the Jackson of the Gulf province.

MIOCENE

The marine Miocene of the West Coast is divisible, both on the basis of stratigraphy and fauna, into two major series each of which contains minor horizons.

The portion of the geological section referable to the Monterey series (Lower-Middle Miocene) contains two fairly distinct faunas and two epochs of deposition, at least in certain areas of the state of California. The lower of these two divisions is the Vaqueros group, sometimes referred to as the "Turritella inezana" zone. The upper division of the Monterey series is herein referred to as the Temblor group and is represented by the fauna of the "Turritella ocoyana" zone. The deposits of the Vaqueros Sea covered a much more limited area than those of the Temblor, and have not been found in Oregon or Washington.

[1] R. E. Dickerson, "Climate and Its Influence upon the Oligocene Faunas of the Pacific Coast with Descriptions of Some New Species from the Molopophorus Lincolnensis Zone." *Proc. Cal. Acad. Sci.*, Fourth Series, Vol. VII (1917), No. 6, pp. 157–92.

The upper major Miocene division constitutes the San Pablo series, which is composed of three minor stratigraphic and faunal divisions, the Briones, Cierbo, and Santa Margarita groups. As will be brought out later, each one of these groups represents a distinct sequence of deposition and possesses a fairly distinctive fauna.

Monterey series.—Whether or not the Vaqueros and Temblor represent separate stratigraphic units has been the source of considerable disagreement in time past.[1] Nearly everyone, however, who has studied the fossils obtained from these beds has agreed that there are two fairly distinct, though closely related, faunas, one the fauna of the Turritella inezana zone, the other that of the Turritella ocoyana zone.

Recent stratigraphic and paleontological work, the results of which are still unpublished,[2] appears to show that at certain localities in California there were crustal movements of considerable magnitude between the deposition of the Vaqueros and the Temblor. The proper valuation of this hiatus is, in the writer's mind, still an open question. The faunas appear to be fairly closely related, and because of the obscure stratigraphic relations at various localities and the general similarity of the faunas the groups have usually been thrown together. The United States Geological Survey, in its more recent publications on Coast Range geology, applies the name "Monterey group" to these deposits, but the writer considers the Monterey a "series" because, at least in certain localities, it is composed of two epochs of deposition, the Vaqueros and the Temblor.

Stratigraphic relations of the Monterey series to the Upper Oligocene.—There is no conclusive evidence that there were any great

[1] G. D. Louderback, "Monterey Series of California," *Bull. Dept. Geol., Univ. Cal.*, Vol. VII (1913), No. 10, pp. 177–241. F. M. Anderson, "Stratigraphic Study of the Mount Diablo Range of California," *Proc. Cal. Acad. Sci.*, Third Series, Vol. II (1905), No. 2, pp. 161–248. F. M. Anderson, "Further Study of the Mount Diablo Range of California," *Proc. Cal. Acad. Sci.* Fourth Series, Vol. III.

[2] Mapping by Dr. Kew of the United States Geological Survey shows an important unconformity in southern California between the Temblor and the Vaqueros. Mr. Wayne Loel, formerly of Leland Stanford University, is working on a monograph of the Vaqueros. He believes that the faunas of the Temblor and the Vaqueros represent two distinct horizons.

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crustal movements just previous to the deposition of the Vaqueros. However, that there was an important hiatus following the deposition of the San Lorenzo is brought out by a comparison of the San Lorenzo and Vaqueros faunas. Very few of the species of the San Lorenzo (Upper Oligocene) have been found in the Vaqueros, while a very large percentage of the species of the latter horizon are common to the Temblor. It is this great faunal change between the San Lorenzo and Vaqueros that is most significant and indicative of one of the major breaks.[1]

Correlation of the Temblor and Vaqueros.—As in the case of the Oligocene, very little direct evidence has been obtained for the correlation, on the basis of the invertebrates, of the divisions of the Monterey series with the Lower-Middle Miocene of the eastern province and Europe. These deposits of the Monterey series were first referred to the Miocene by Conrad[2] as early as 1837. This determination was made chiefly on the general similarity of the generic assemblages to the faunas of the Atlantic Coast Miocene. Following Conrad, the beds here referred to the Monterey series were determined by Whitney and Gabb, both of the old California State Geological Survey, as Miocene. No attempt was made by these pioneers to recognize any subdivisions in the Miocene. Beds now recognized as Upper Miocene (San Pablo) were called Pliocene by Whitney and Gabb[3].

The first announcement of a correlation which gave a fairly definite position to the Temblor group appeared in a paper by Professor J. C. Merriam, entitled "Tertiary Vertebrate Faunas of the North Coalinga Region of California."[4] Previously the Temblor had been referred by some geologists to the Lower Miocene and by others to the Oligocene. In the region of North Coalinga

[1] B. L. Clark, "San Lorenzo Series of Middle California," *Bull. Dept. Geol., Univ. Cal.*, Vol. XI (1918), No. 2, p. 105.

[2] T. A. Conrad, "Fossils from Northwestern America," *Geol. U.S. Ex. Exped.*, Vol. I (1849), App., pp. 723–29, Pls. 17–20; *Proc. Acad. Nat. Sci. Phila.*, Vol. VII (1837), p. 441.

[3] W. M. Gabb, *California Geological Survey: Palaeontology*, Vols. I and II (1864–69).

[4] J. C. Merriam, "Tertiary Vertebrate Faunas of the North Coalinga Region of California," *Trans. Am. Phil. Soc.*, New Series, Vol. XXII (1915), Part III, pp. 1–44.

the land formation locally known as the Big Blue was intercalated with beds of Temblor age from which good marine faunas have been obtained.[1] The Big Blue was first considered by Arnold and Anderson[2] as a part of the Santa Margarita (Upper Miocene). Later mapping, however, showed that it is more closely connected to the Temblor (the so-called Vaqueros) than to the Santa Margarita of that section.

In describing the fauna obtained from the Big Blue, Merriam says:

> In terms of the vertebrate series of Western North America the fauna of the Merychippus zone in the north Coalinga region is clearly later than lower Miocene and not later than upper Miocene. The fact that the Big Blue comes in a section where the Temblor deposits are very thin, and we think are only the top of that section, makes it seem reasonable to believe that the Temblor deposits as a whole belong to the middle Miocene rather than to a part of the upper Miocene.[3]

A clue to the age of the Vaqueros deposits was obtained very recently by the discovery of land-laid deposits near the south end of the San Joaquin Valley which are intercalated with marine deposits of the Vaqueros age. Beds containing a Vaqueros fauna are found immediately below these land-laid beds, and the marine beds immediately above are believed to represent the same horizon. The announcement of the discovery of a vertebrate fauna obtained from these land-laid beds associated with the Vaqueros was recently made by Dr. Chester Stock.[4] These land-laid deposits, referred to as the Tecuja beds, were tentatively correlated by Dr. Stock with the John Day horizon of Oregon. He reports the presence of the genus *Hypertragulus*, a form related to the early camels and deer. *Hypertragulus* occurs both in the Upper Oligocene and the Lower Miocene, but the species from the Tecuja beds seems more

[1] The beds mapped as Vaqueros in the Coalinga field by the United States Geological Survey belong to the Temblor horizon rather than to the Vaqueros.

[2] R. Arnold and R. Anderson, "Geology and Oil Resources of the Coalinga District of California," *U.S. Geol. Surv., Bull. 396* (1909), p. 90.

[3] J. C. Merriam, "Tertiary Vertebrate Faunas of the North Coalinga Region of California," *Trans. Am. Phil. Soc.*, New Series, Vol. XXII (1915), Part III, p. 20.

[4] Chester Stock, "An Early Tertiary Vertebrate Fauna from the Southern Coast Ranges of California," *Bull. Dept. Geol., Univ. Cal.*, Vol. XII (1920), No. 4, pp. 267–76.

closely related to the John Day (Upper Oligocene) form than to that found in the lower Rosebud (Lower Miocene) of the Great Basin region. While Dr. Stock has indicated the relationships of of the Tecuja vertebrate fauna to that of the John Day, he has also stated that it may occupy a position in the Tertiary transitional between Oligocene and Miocene. It seems to the writer that the stratigraphic and paleontologic evidence favors the Lower Miocene age of these beds rather than the Upper Oligocene. The most important evidence in favor of this last conclusion is that the invertebrate fauna of the Vaqueros as already stated, is very closely related to that of the Temblor, a very large percentage of the species being common to the two faunas. Some of the forms listed are types of considerable ornamentation and complexity and are known to have a fairly short geological range. On the other hand, the known fauna of the Vaqueros is very different from the known fauna of the San Lorenzo, and there is here a much greater faunal break than between the Vaqueros and the Temblor. In the section at the south end of the San Joaquin Valley, where the Tecuja beds occur, the Vaqueros rests directly and unconformably upon the San Lorenzo.

Climate.—The conditions of temperature during the Vaqueros and Temblor epoch seem to have been between warm-temperate and subtropical. The generic assemblages of the two horizons are very similar. The large lyropectens and dosinias are found in both, and a fairly high percentage of the species are common to the two horizons. This close relationship of the faunas indicates a similar temperature of the waters.

One of the puzzling problems in connection with the origin of the Temblor deposits is the great thickness of organic shales that is found all along the coast of California and especially in the southern part of the state. In some localities these organic shales, a very large proportion of which are composed of the frustules of marine diatoms, have a thickness exceeding 5,000 feet. Diatomaceous oozes in any considerable quantity are now only found in Arctic and Antarctic waters, and from this we might judge that these shales were deposited in cold water. However, the fossil molluscan faunas found in these shales, or closely associated with them,

indicate a moderate temperature. Dr. J. C. Branner, in a paper read before the Cordilleran Section of the Geological Society of America, suggested an explanation of this apparent disagreement between the floral and faunal evidence.[1] The great thickness of diatomaceous shales in southern California is to be explained by the hypothesis that cold currents carried the diatoms southward along the coast and finally into the partially land-locked basins of southern California where they were killed by the change in temperature. The continuous supply from the north resulted in great thicknesses of deposits composed largely of the tests of these minute plants. This hypothesis may also be an explanation of the origin of the diatomaceous shales of the Oligocene and Upper Miocene.

Paleogeography.—The Temblor deposits have much wider distribution than those of the Vaqueros (Figs. 6 and 7) and are found on the eastern as well as the western side of the Coast ranges. On the eastern side from the vicinity of Coalinga northward these deposits are composed of coarse clastics, while to the west organic shales cover the larger part of the section. The comparison of the area covered by this sea with that which existed during Lower Oligocene time (when the Kreyenhagen shales were deposited), (Fig. 4) shows a marked change. As has already been stated, the Oligocene sediments were deposited in an inland north–south trough very similar to that which existed during the Eocene. The deepest part of the Oligocene trough was on the eastern side of the present Coast ranges, a very large part of the western side at that time apparently having been subject to erosion. On the other hand, the deepest part of the Temblor sea was on the western side of the present Coast ranges; the areas which had been land during the Oligocene were inundated, while to the east, where the Oligocene trough had been deepest, the strand-line deposits indicate shallow water conditions. At this time the interior Diablo range probably formed an archipelago of islands.

San Pablo series.—The San Pablo series is recognized as the second major division of the Miocene. Like the San Lorenzo and

[1] J. C. Branner, "Influence of Wind on the Accumulation of Oil-bearing Rocks," *Proc. Thirteenth Ann. Meeting of the Cordilleran Section of the Geol. Soc. of Am., Bull. Geol. Soc. Am.*, Vol. XXIV (1913), pp. 94–95.

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Monterey series, the San Pablo is divisible into minor units on the basis of stratigraphy and fauna. The faunal changes and disconformable relationships of the beds indicate that the sea advanced and retreated three times in middle California, during this period. It is only in middle California that we find the complete sequence of the Upper Miocene series. The two lower divisions of the San

FIG. 6.—Vaqueros (lower Monterey, Miocene)

Pablo series, the Briones and Cierbo groups,[1] have been recognized only in the general region of San Francisco Bay.

Stratigraphic relationships.—In certain sections immediately east of or in the Salinas Valley, a distance of not more than 100 miles

[1] The use of the term San Pablo for the Upper Miocene series of deposits on the West Coast makes it necessary to dispense with the term San Pablo within the group. The name Cierbo is therefore used in this paper in referring to the middle group of the San Pablo series. The type section of the Cierbo is in the south side of the Canada del Cierbo near Carquinez straits. Santa Margarita is a name in common use for the upper portion of the section in the southern part of the state of California and will be applied as a general name for the upper member of the San Pablo series.

from the San Francisco Bay area, we find evidences of crustal movements between the Temblor and the Santa Margarita which have been described as mountain-making. In the Salinas Valley region it is not uncommon to find the difference in dip between the Temblor and the Santa Margarita as much as 30° to 90°, together

FIG. 7.—Temblor (upper Monterey, Miocene)

with marked difference in strike. Dr. Arnold, in describing the movements that caused this unconformity, says:

> One of the most widespread and important periods of diastrophism in the Tertiary history of the Pacific Coast was that immediately following the deposition of the Monterey or lower middle Miocene. Its effects are visible from Puget Sound to southern California It is marked as much by readjustment, by local faulting and folding as by general movements of elevation and subsidence. In some regions the folding and faulting were intense, the greatest disturbances accompanying the uplift of the mountain ranges to an altitude of thousands of feet. In other regions low broad folds were formed during the

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post-Monterey disturbance, and the strata were not upheaved to a great altitude. Faulting on a most magnificent scale took place along the earthquake rift and certain other fault-zones, especially that in the Salinas Valley, and along these lines of displacement, masses of granitic rocks, which during the preceding epoch had been subject to little or no erosion, were suddenly thrust upward and left exposed to the ravages of streams that assumed the proportions of torrents in certain regions, as for instance adjacent to the Carrizo Plain in south-central California. The post-Monterey diastrophic movements in the Puget Sound province also produced sharp relief as is evidenced by the coarse sediments immediately following the disturbance. The localization of movements during the period is exemplified at numerous localities in the Coast Ranges.

Throughout much of the coastal belt, and probably likewise in the interior, great volcanic activity took place during the middle Miocene, this being the last epoch of volcanism in the Coast Ranges, south of San Francisco Bay.[1]

It is interesting to note that only a comparatively short distance to the east of the southern Salinas Valley area, where the great unconformity between the Temblor and the Santa Margarita deposits is best seen, it has been very difficult to find the line separating these two horizons. Both the Santa Margarita and Temblor deposits to the southwest of the San Joaquin Valley are composed of organic shales, and in consequence of the difficulty in separating the two horizons the United States Geological Survey has applied the name Maricopa shale to the deposits as a whole.[2] No marked stratigraphic break has been found in middle California between the deposits of the lower San Pablo series (Briones group) and those representing the Temblor. Here the beds of these two horizons are parallel, the chief basis for making the separation being irregular contacts and the difference between the faunas. In middle California, therefore, we have no evidence of crustal movements immediately after the deposition of the Temblor.

Correlation.—Direct evidence for the correlation of the San Pablo series with the eastern and European sections is lacking. The writer has presented the evidence for the correlation of this

[1] R. Arnold, "The Environment of the Tertiary Faunas of the Pacific Coast of the United States," in Willis *et al.*, *Outlines of Geology* (1910), p. 241.

[2] R. W. Pack, "Geology and Oil Resources: Sunset-Midway Oil Field, California," *U.S. Geol. Surv., Prof. Paper 116* (1920), p. 35.

group in a former paper. The correlation is based upon an analysis of the molluscan fauna by the percentage method and the evidence afforded by the occurrence of vertebrates in beds immediately above and below the San Pablo. The following quotations are taken from the above-mentioned paper:

> The percentage of Recent molluscan species in the San Pablo of middle California as listed by the writer is 23 plus; as based upon the gastropods the percentage is only 11 per cent. If we use the percentages as applied to the east coast Neocene and if we can rely upon the equal refinement in the determination of the species, the San Pablo may be considered to be upper Miocene in age, possibly lower Pliocene.
>
> Probably the best evidence showing the age of the uppermost beds of the San Pablo of middle California comes from vertebrate material obtained in the fresh-water beds which in middle California overlie unconformably the San Pablo group. This material was described by Professor J. C. Merriam in his paper "Vertebrate Fauna of the Orinda and the Siesta Beds in middle California."[1] His conclusions as to the age of these beds as shown by the vertebrates are as follows: "The mammalian remains known from both the Orindan and Siestan up to the present time all represent forms such as might be expected in the late Miocene or in the earliest Pliocene, but it will be necessary both to have better material from the Orindan and Siestan and to have well known faunas of western Miocene and Pliocene for comparison before the last word on the age determination can be pronounced.
>
> "Considering the indefiniteness of all the factors concerned, one would not seem justified in being more definite than to state that the Orindan and Siestan faunas are near a late Miocene stage. When the faunas of the two formations are better known, it may appear that more than one stage is represented."[2]

The reader will remember from the discussion of the age of the Temblor that the vertebrate fauna obtained from the Big Blue formation, which is apparently intercalated with the Temblor deposits in the north Coalinga region, was determined by Dr. J. C. Merriam as being not earlier than Middle Miocene. In this same section the Santa Margarita formation is found unconformably above the Big Blue and marine Temblor beds. Also, as will be brought out in the discussion of the Pliocene, a Lower Pliocene vertebrate fauna was found in land-laid beds which rest unconform-

[1] J. C. Merriam, "Vertebrate Fauna of the Orindan and Siestan Beds in Middle California," *Bull. Dept. Geol., Univ. Cal.*, Vol. VII (1913), No. 19, pp. 373–85.

[2] B. L. Clark, "The Fauna of the San Pablo Group of Middle California," *Bull. Dept. Geol., Univ. Cal.*, Vol. VIII (1915), No. 22, p. 439–42.

ably upon the top of the Santa Margarita. Thus it would seem that if we can trust the correlation on the basis of the vertebrates, there can be very little doubt as to the age of the Santa Margarita group which comes between two vertebrate horizons, one not earlier than Middle Miocene, the other not later than Lower Pliocene.

Climate.—The paleontological evidence seems to show that, beginning with the Upper Miocene, there was a temperature differentiation on the West Coast that was even more marked than that existing today.

The Briones and Cierbo groups (lower and middle San Pablo) are not found in southern California, and because of their limited distribution give us very little evidence of temperature differentiation.

The fauna obtained from the Santa Margarita (upper San Pablo) in middle California may be regarded as approximately warm-temperate, and if it were now living it would probably not be found south of Santa Barbara County. This conclusion is based upon the large percentage of recent species found in the faunal assemblage and common to the fauna now found living between San Francisco Bay and Santa Barbara. The presence of certain recent species and the absence of certain genera found at northern localities indicate that the Santa Margarita horizon in southern California represents a warmer facies than that found in middle California. There is, however, a sufficient number of distinctive species common to the two horizons to establish their correlation, though the faunas are on the whole very different.

The fauna of the Montesano formation of Washington, described by Dr. C. E. Weaver,[1] is apparently Upper Miocene in age, but just what part of the San Pablo series it represents has not been established. This fauna, judging from the recent genera and species in the assemblage, is boreal and consequently very different from that of the San Pablo. If the correlation of the Montesano formation with the San Pablo series is correct, there was at that time a temperature differentiation comparable to that found between the recent faunas of middle California and Alaska.

[1] C. E. Weaver, "Tertiary Formations of Western Washington," *Wash. Geol. Surv., Bull. 13* (1916), pp. 1–327.

Paleogeography.—The sediments of the Briones and Cierbo groups were deposited in a limited arm of the sea confined to the San Francisco Bay region (Figs. 8 and 9). Where all the groups of the San Pablo series are present, erosion contacts are found separating them.

With the opening of the Santa Margarita there was a great inundation, somewhat comparable to that of the Temblor, though

FIG. 8.—Briones (lower San Pablo, Miocene)

the basins of the former were more local. Beds of Santa Margarita age are found from a little north of San Francisco to the region just north of Los Angeles (Fig. 10). The deposits are found on both the eastern and the western sides of the Coast ranges, and over large areas to the south of San Francisco these deposits are composed very largely of organic shales of considerable thickness.

PLIOCENE

The marine Pliocene of the West Coast as now recognized is divisible into at least three distinct horizons: the Jacalitos, the Merced, and the Saugus. Continental deposits are found in different parts of the Coast ranges representing all three of these horizons, and in some instances to which reference has already been made these continental deposits are found closely associated with the marine beds.

FIG. 9.—Cierbo (middle San Pablo, Miocene)

Stratigraphic relationship of the Pliocene and Upper Miocene.—No evidence of folding between the beds of the Santa Margarita (Upper Miocene) and the Jacalitos (Lower Pliocene) has been obtained in southern California, though good erosion contacts are found separating them and the faunas are on the whole very different. In the vicinity of Mount Diablo, just to the east of the San Francisco region, the Santa Margarita beds were folded before the

Lower Pliocene deposits were laid down. The Lower Pliocene in this region is composed of the Pinole tuff and the Orinda formation which are of continental origin.

Faunal relationships of the Pliocene.—Dr. Nomland's study of the faunas of the Jacalitos ("lower Etchegoin") and Santa Margarita has shown that they are very distinct, and that the hiatus between them was more than local.[1] None of the highly ornamented gastropods, pelecypods, or echinoids has been found common to the two, and the percentage of recent species in the Santa Margarita is much less than that in the Jacalitos (lower Etchegoin) of Nomland.

An unconformity has been found in the Fernando series in the region just north of Los Angeles which is probably the largest and most important stratigraphic break in the West Coast marine Pliocene.[2] Over a fairly large area in that region there is a marked difference in dip and strike between the lower and middle Fernando, now referred to the Pico formation by the United States Geological Survey, and what has previously been referred to as the upper Fernando.[3] The beds of this upper horizon contain a very large percentage of recent species. The Geological Survey proposes to use the name "Saugus formation" for the upper Fernando section. It is herein referred to as the Saugus group. The faunal break between the Saugus and the Pico indicates a great lapse of time. Indeed, the difference is so great that the question may be raised as to whether the Saugus does not belong to the Pleistocene

[1] J. O. Nomland, "Fauna of the Lower Pliocene at Jacalitos Creek and Waltham Canyon, Fresno County, California," *Bull. Dept. Geol., Univ. Cal.*, Vol. IX (1916), No. 14, pp. 199–214; "Fauna of the Santa Margarita Beds in the North Coalinga Region of California," *Bull. Dept. Geol., Univ. Cal.*, Vol. X (1917), No. 18, pp. 293–326.

[2] G. H. Eldridge, and R. Arnold, "Santa Clara Valley, Puente Hills and Los Angeles Oil Districts of California," *U.S. Geol. Surv., Bull. 309* (1907), pp. 1–259. R. Arnold and R. Anderson, "Geology and Oil Resources of the Santa Maria District, California," *U.S. Geol. Surv., Bull. 322* (1907), pp. 1–157. W. S. W. Kew, "Structure and Oil Resources of the Simi Valley, Southern California," *U.S. Geol. Surv., Bull. 691 M* (1919), pp. 323–55.

[3] A paper by Dr. W. S. W. Kew of the United States Geological Survey is now in press in which the Fernando is considered a group composed of the Pico and Saugus formations separated by an unconformity.

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rather than to the Pliocene. If so, the West Coast Pleistocene formations have been generally folded.

Correlation.—There has been considerable confusion in times past as to the proper sequence of the Pliocene. The difficulties appear to have been due to two factors: first, the basins of deposition during the Pliocene were more local and isolated than they had

FIG. 10.—Santa Margarita (upper San Pablo, Miocene)

been during previous periods; and second, conditions of temperature varied from one locality to another. These factors were undoubtedly the cause of the great differences found between the faunas of the various provinces; however, the latter factor, temperature, was the most important. The great confusion as to the proper sequence of the Pliocene formations is reflected in the numerous names which have been given to them. Beginning

in Oregon, we have the "Empire" formation;[1] in northern California, the "Wildcat";[2] in the region of San Francisco Bay, the "Merced";[3] and a little to the south of this, in Santa Cruz County, is the "Purissima."[4] Still farther to the south are the "Jacalitos" and "Etchegoin" formations in the Coalinga region;[5] the "Pico" and "Saugus" formations of the Fernando group[6] in the Ventura region and the "San Pedro"[7] and "San Diego" Pliocene deposits on the southern California coast. The "Purissima," "Jacalitos," "Etchegoin," and "lower Fernando" have in the past been referred to the Upper Miocene and correlated with the San Pablo of middle California.

During the last few years our ideas of the sequence of these various formations have been very radically revised as the result of more detailed studies of vertebrate and invertebrate faunas. The writer's study of the San Pablo series convinced him that the faunas of that series belong to an older horizon than those of the Jacalitos-Etchegoin, Purissima, and Pico, and that the percentage of recent species in the latter beds indicate Pliocene age. Later work by Dr. Nomland on the Jacalitos and Etchegoin of the Coalinga region corroborated these conclusions.

[1] W. H. Dall, "The Miocene of Astoria and Coos Bay, Oregon," *U.S. Geol. Surv., Prof. Paper 59* (1909), pp. 1–261.

[2] A. C. Lawson, "The Geomorphogeny of the Coast of Northern California," *Bull. Dept. Geol., Univ. Cal.*, Vol. I, No. 8 (1894), pp. 24–272. Bruce Martin, "Pliocene of Middle and Northern California," *Bull. Dept. Geol., Univ. Cal.*, Vol. IX (1916), No. 15, pp. 215–59.

[3] A. C. Lawson, *U.S. Geol. Surv., Folio 193*, San Francisco Folio; "Post-Pliocene Diastrophism of the Coast of Southern California," *Bull. Dept. Geol., Univ. Cal.*, Vol. I, No. 4 (1893), pp. 115–60.

[4] J. C. Branner, F. G. Newsom, and R. Arnold, *U.S. Geol. Surv., Folio 163*, Santa Cruz Folio.

[5] J. O. Nomland, "Fauna of the Lower Pliocene at Jacalitos Creek and Waltham Canyon, Fresno County, California," *Bull. Dept. Geol., Univ. Cal.*, Vol. IX (1916) No. 14, pp. 199–214; "Etchegoin Pliocene of Middle California," *Bull. Dept. Geol., Univ. Cal.*, Vol. X (1917), No. 14, pp. 191–254. R. Arnold, "Palaeontology of the Coalinga District, California," *U.S. Geol. Surv., Bull. 396* (1909), pp. 5–169.

[6] W. A. English, "Fernando Group near Newhall California," *Bull. Dept. Geol., Univ. Cal.*, Vol. VIII (1914), No. 8, pp. 203–8.

[7] R. Arnold, "Palaeontology and Stratigraphy of the Marine Pliocene and Pleistocene of San Pedro, California," *Cal. Acad. Sci., Memoir III* (1903).

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The most conclusive evidence of the Pliocene age of the Jacalitos and Etchegoin was the discovery of fossil land vertebrates in these formations in the Coalinga district. These vertebrate remains were obtained from three distinct horizons: one in what has been mapped as Jacalitos, another in the middle of the type section of the Etchegoin, and the third at the top of the Etchegoin. Professor J. C. Merriam, to whom this material was referred for study, has determined these faunas to be of Pliocene age. Merriam referred to the lowest fauna, that of the Neohipparion zone, as being not older than Lower Pliocene.[1] The next horizon is fairly well up in the Pliocene, and the fauna from the upper Etchegoin is referred to the Upper Pliocene.

It is interesting to note that stratigraphically above the Pliohippus proversus beds of Merriam (uppermost Pliocene), in the above-mentioned section, there are several thousand feet of land-laid deposits which are folded and are older than the Pleistocene terraces of that region. No evidence of the exact age of these beds has been obtained, but it is suggested that they may be the land-laid equivalent of the Saugus of that vicinity.

Climate.—One of the most interesting results of the study of the invertebrate faunas of the Pliocene is the evidence they give of temperature differentiation. The fauna from the Wildcat and Merced of northern and middle California is essentially boreal in character. In southern California the Pliocene is for the most part represented by a fairly warm-temperate fauna. These two faunas, the boreal and the warm-temperate, have very little in common, and consequently it was a long time before their contemporaneity was recognized. The solution of the problem was obtained from the fauna of an intermediate area. The fauna of the type section of the Purissima in the Santa Cruz Mountains of California is in part warm-temperate and in part boreal, and certain species very common in the north, some of which are fairly highly ornamented forms, were found in this section.

Paleogeography.—It was noted in the first paragraph, under the discussion of the factors causing the differentiation of faunas of

[1] J. C. Merriam, "Tertiary Vertebrate Faunas of the North Coalinga Region of California," *Amer. Phil. Soc. Trans.*, N.S. Vol. XII, Pl. III (1915), pp. 26–43.

the Pliocene, that the basins of deposition were local. Crustal movements appear to have been more frequent during the Pliocene than during the other periods of the Tertiary, and we may therefore expect to find a large number of stratigraphic breaks which do not represent any very great time break. At the opening of the Pliocene the Jacalitos sea was much more limited than the seas of

FIG. 11.—Merced (Middle Pliocene)

the Middle or possibly the Upper Pliocene, and the principal localities where deposition took place were probably in the region of the southern and western side of the San Joaquin Valley and the southern part of the Salinas Valley. This sea was probably connected with the ocean in the vicinity of the upper Salinas Valley.

With the opening of the middle Pliocene a great change had taken place. The sea transgressed over wide areas to the north. Areas which had previously been subject to erosion were covered.

This great incursion is referred to here as the Merced sea and represents the time of deposition of the Purissima, Etchegoin, and Jacalitos (Fig. 11). The condition was similar to that which existed in the Upper Miocene, when there were restricted basins at the opening of the period, a great incursion during the later part of the period, and then a retreat shown by widespread unconformities.

FIG. 12.—Saugus (Upper Pliocene)

The Saugus formation, of which little is known, appears to have been formed after the folding and consequent retreat of the sea from the great inland basins in the San Joaquin and Salinas Valley districts. The Saugus beds are largely confined to the coast, but in the Ventura district an embayment extended a considerable distance inland (Fig. 12).

The Pliocene period was followed by great crustal movements which folded the formations in great anticlines and synclines, some

of which were overturned. In certain localities the Cretaceous has been thrust over the younger formations. Though this great period of crustal movement had its culmination at the close of Saugus time, it was well under way even prior to the deposition of these beds. In the past geologists have generally assumed that the division between the Pliocene and Pleistocene occurs after this great folding, that is, at the end of Saugus time. But the very large percentage of the Recent species in the Saugus suggests that the group may possibly be of Pleistocene age, and therefore a large part of the folding which created the Coast ranges may have taken place during Pleistocene time.

OUTLINE OF PLEISTOCENE HISTORY OF MISSISSIPPI VALLEY[1]

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RELATION OF PRESENT STREAM TO PREGLACIAL VALLEYS

The headwater portion of the Mississippi River, above St. Paul, Minnesota, is in a region so thickly covered by glacial deposits that the present streams are entirely independent of the preglacial valleys, and their history begins with the recession of the ice in the last, or Wisconsin, stage of glaciation. The courses of preglacial drainage lines in this region have been only partially traced by means of deep borings. This paper deals, therefore, mainly with the part below St. Paul.

For 15 miles below St. Paul the Mississippi follows the valley of a small tributary of the preglacial river, the course of the main valley being a few miles to the west, passing beneath Lake Minnetonka, and across the lower end of Minnesota Valley, and continuing through Dakota County to the present stream at Pine Bend, 6 miles above Hastings. From Hastings to Clinton, Iowa, the river practically follows the course of the preglacial valley, though it cuts off projecting points from the west bluff at Trempealeau, Wisconsin, and in the north part of Clinton, Iowa (Fig. 1).

At the mouth of the Wapsipinicon River, below Clinton, the Mississippi leaves the preglacial valley, passes into a rock gorge, and flows across rapids to Rock Island. Two courses for the preglacial valley have been suggested, one to the southwest from the lower part of Wapsipinicon Valley to Muscatine, on the present Mississippi, the other to the southeast to Hennepin, on the Illinois Valley. Along both lines the glacial deposits are very thick, and the rock surface much lower than the present streams. The southeastward course seems on the whole more likely to have been

[1] Published by permission of Director, U.S. Geological Survey.

FIG. 1.—Map of Mississippi River

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followed by the preglacial Mississippi, for other preglacial valleys converge toward it, one followed by the lower course of the Rock River, reversed, and another by Duck Creek, and its continuation in an abandoned valley to the east of Rock Island. The breadth of the valley leading to the Illinois also appears to be greater than that of the one to the southwest. A different stream from that which opened the upper Mississippi Valley probably developed the valley now utilized by the Mississippi below Muscatine. It is likely to have taken the drainage of much of eastern Iowa and drained the region now tributary to Iowa River, though it does not follow the course of that stream. It may, perhaps, be appropriately called the preglacial Iowa River.

The two drainage lines came together at the mouth of the Illinois River. The western one departed slightly from the present Mississippi in the southeast corner of Iowa, the old course being southwest from Fort Madison to the mouth of the Des Moines River, while the present stream turns southward across the Des Moines rapids to Keokuk, and joins the old valley at Warsaw, Illinois.

The present river follows essentially the course of the preglacial valley from the mouth of the Illinois River to Thebes in southern Illinois, though it has cut off points from the west bluff near Grand Tower, which in high-water stages stand as islands in the valley. The Mississippi turns into a rock gorge at Thebes, and a few miles below comes into the old Ohio Valley, while the old valley runs southwestward, and unites with the Ohio Valley farther down.

RELATION OF PRESENT STREAM BED TO BURIED ROCK FLOOR

The present stream falls from 683 feet A.T. at St. Paul to 566 feet at Clinton, or 117 feet in about 300 miles. This section includes Lake Pepin which holds a level of 664 feet for 25 miles. Aside from this lake the stream has an average fall of about 5 inches per mile. The fall of the buried rock floor is very similar, for it stands 480 to 500 feet A.T. near St. Paul and is below 400 feet in the vicinity of Clinton. The rock floor has more or less inequality because of variations in the scour of the stream, and in the hardness

of the bed, so its slope conforms only in a general way with that of the stream which occupied it.

On the line of the old valley leading from Clinton southeastward to the Illinois River at Hennepin the rock floor falls to about 340 feet, as shown by borings at Princeton and Bureau Junction, near Hennepin. The Illinois River at Hennepin is 432 feet A.T. or about 90 feet above the rock floor.

The Illinois River has a fall of only 27 feet in 207 miles from Hennepin to the junction with the Mississippi River, or 1.56 inches per mile. From the mouth of the Illinois River to St. Louis, a distance of 41.5 miles, the Mississippi falls 21 feet, or 6 inches to the mile. The rock floor, as shown by borings and bridge excavations opposite St. Louis, is about 100 feet below the low-water level of the river, or 280 feet A.T. This gives a fall of 60 feet from Hennepin to St. Louis in 248 miles, or about 3 inches per mile.

The distance by the course of the present Mississippi from Clinton to St. Louis is about the same as along the line to Hennepin and down the Illinois, being not far from 300 miles. The fall is about 180 feet, of which 48 feet is over rock rapids in a distance of 24 miles. The remaining 132 feet is at the rate of less than 6 inches per mile. The rock floor in the valley below Muscatine is known to be 100 feet or more below low water. It has been best tested at Fort Madison, and found to be 120 to 135 feet below low water, or 365 to 380 feet A.T. There is thus a fall of nearly 100 feet between Fort Madison and St. Louis in about 200 miles, or a rate very similar to that of the present stream, aside from the rapids.

The fact that these buried valleys have beds 100 to 180 feet below the low-water level of the present streams has led certain geologists to infer that the altitude must have been higher than now when they were excavated. There are, however, certain other conditions that have had influence in causing this difference. One of these conditions is a marked lengthening of the lower course of the Mississippi, or extension of its mouth gulfward, in the long period since the river was flowing on this rock bed. Warren Upham has presented evidence from a study of old maps of the lower course of the Mississippi that the delta has made a marked

extension in the past 400 years.[1] The time since glaciation came in to displace the streams from their preglacial beds is likely to be at least 1,000 times, and perhaps 2,000 times, as long as the 400 years involved in the growth noted by Upham. The extension may, therefore, be as great as from the site of Vicksburg, and perhaps from farther up. With this lengthening there would come a corresponding aggradation of the valley causing the stream to flow at a level materially higher than its rock bed. Studies by the present writer near Osceola in the northeast part of Arkansas have shown that the flood plain has been built up about 35 feet by a sediment finer than the underlying sand presumably in Pleistocene time. So the aggradation there appears to have been at least that amount, and it would be fully as great farther up the valley.

Another condition that affects the Mississippi Valley below the mouth of the Missouri River, results from the greater amount of sediment now brought in by that stream and carried down the Mississippi, as compared with that likely to have been carried by it before its watershed became so extensively covered with loess, for loess furnishes the main part of the sediment. With increase of load a stream raises its gradient. The Missouri has a fall of about 300 feet in its lower 300 miles, while the section of the Mississippi which is less heavily loaded with sediment has a fall of only about 150 feet. Below their junction the stream has a slightly higher rate of fall than that of the Mississippi above the junction, it being 7.2 inches per mile from the mouth of the Missouri to the mouth of the Ohio. The effect of this load of sediment is clearly brought out by comparing this section of the Mississippi with the section of the Ohio immediately above its mouth. The rate of fall in the lower 200 miles of the Ohio is only about 3 inches per mile, or less than half that of the Mississippi; yet the Ohio is a smaller stream, and should have a higher gradient were it carrying a similar load. There is a difference of about 70 feet between the fall of the Mississippi and of the Ohio in the 200 miles above their junction, and this may give a measure of the amount of aggradation at the mouth of the Missouri, due to the heavy load

[1] "Growth of the Mississippi delta," *American Geologist*, Vol. XXX (1902), pp. 103–11.

of sediment. If to this is added the 35 feet of aggradation that is due to the lengthening of the stream, the full difference between the level of the rock bed and the level of the present river is accounted for. There thus seems no need for postulating disatrophic movement. Farther up the river the rock barriers in the path of the stream, above Keokuk and above Rock Island, contribute in holding the present stream to a high level.

GLACIATION IN ITS RELATION TO DRAINAGE MODIFICATION

The preglacial Mississippi in its course from near Red Wing in southeastern Minnesota to the lower Illinois valley, and thence to St. Louis and Cairo, appears to have suffered little or no disturbance in the first two stages of glaciation, the Nebraskan, or pre-Kansan, and the Kansan. The Iowa branch of the preglacial Mississippi was more seriously disturbed by these early glaciations. Its valley was so completely filled as far down as Muscatine that its course is known only by borings. It was also completely filled for a few miles in the southeastern corner of Iowa. The filling as far down as the line of Iowa and Missouri is found to embrace the pre-Kansan as well as Kansan drift. In the vicinity of Fort Madison, Iowa, the pre-Kansan drift fills the old valley from the level of the rock floor, 135 feet below the present stream, to a height of about 75 feet above the river. A black soil marks its upper limit. It is overlain by Kansan drift, and this in turn by Illinoian drift, which rests on a soil developed on the Kansan drift. Other records in eastern Iowa, southern Minnesota and western Wisconsin show that valley excavation had reached its lowest limits prior to the earliest glaciation. One of the clearest records is at Washington, Iowa, brought to notice by Calvin.[1] It is in a locality where no drift later than the Kansan is present, and is in the line of a western tributary of the preglacial valley utilized by the Mississippi below Muscatine. The Kansan drift extends to a depth of 115 feet, and rests on a peaty bed containing wood and cones of the black spruce. Below this is the pre-Kansan drift, extending to a depth of 350 feet from the surface, or to about 400 feet above sea-level. This level of the rock floor fits in well

[1] *American Geologist*, Vol. I (1888), p. 28.

with that of 365 feet at Fort Madison. Attention is directed particularly to this evidence that the lowest valley excavation is preglacial, since Trowbridge, of the University of Iowa, has for some years been advocating that a large part of the valley deepening in the upper Mississippi region was accomplished between the pre-Kansan and Kansan stages of glaciation.[1]

The Kansan drift extends beyond the present Mississippi Valley into the western edge of Illinois, but does not appear to reach the Illinois Valley. Its southern limits on the border of the Mississippi Valley are at the city of St. Louis. The amount of filling with glacial deposits is difficult to determine because of the great amount of erosion since they were laid down. It was sufficient in southeastern Iowa to prevent the stream from occupying the old valley again. But below the mouth of the Des Moines it was reoccupied by drainage when the ice of the Kansan stage melted away. The course of post-Kansan drainage from the part of the valley between Muscatine and the Des Moines rapids is more difficult to determine, for it was later occupied by ice in the Illinoian stage of glaciation. Possibly it drained eastward from Muscatine, and together with the upper Mississippi discharged through the lower Illinois Valley. It is probable that nearly all the erosion of the gorge at the Des Moines rapids has taken place since the Illinoian stage. A comparison of the valley to the east from Muscatine with that across the Des Moines rapids indicates that it was opened earlier. Its rock bed has been cut below the level of the present Mississippi, and it is a broader valley with gentler slopes than that across the rapids. The difference may be seen by comparing charts 148 and 149 of the Mississippi River Commission, embracing the part east of Muscatine, with charts 136 and 137, which embrace the rapids. The valley east from Muscatine is also embraced in the Edgington and Milan quadrangles of the U.S. Geological Survey. The opening of this valley eastward from Muscatine may date from the Nebraskan stage and have been occupied by east-flowing drainage down to the Illinoian stage, when it was changed to a west-flowing stream.

[1] *Proc. Iowa Academy of Science*, Vol. XXI (1915), pp. 208–9; *University of Iowa Studies*, Vol. IX (1921), pp. 123–27.

It seems probable that the Illinoian glaciation was the first to throw the upper Mississippi out of its course through the Illinois Valley. At the culmination of the Illinoian stage of glaciation the Mississippi opened a temporary course across eastern Iowa, just outside the limits of the ice sheet.[1] This connected with the present Mississippi at the head of the gorge across the Des Moines rapids below Fort Madison at a level about 120 feet above the present stream; so nearly all the cutting in rock at these rapids has been done since that time. The Illinoian drift extends a few miles beyond the present course of the Mississippi from Clinton to Fort Madison, but farther north and south its border lies east of the river. With the recession of the Illinoian ice sheet the Mississippi shifted to its present course between Clinton and Fort Madison.

It seems to have been at this time that the course across the rapids above Rock Island was initiated, the ice being still present on the lower land to the east. The channel across these rapids, like that across the Des Moines rapids, has the appearance of being much younger than that between Muscatine and Rock Island.

Goose Lake channel, which branches off from the present Mississippi at the mouth of Maquoketa River and passes southward across Clinton County, Iowa, to the Wapsipinicon Valley, was probably opened in Illinoian time, and may have continued down to Wisconsin time. It seems, however, to have been abandoned before the waters of the glacial lakes began their work of excavation discussed below.

The glacial drainage outside the Illinoian ice sheet in southeastern Iowa carried enough material into the Mississippi Valley below the Des Moines rapids to fill it to a level about 100 feet above the present low-water level of the river. But within a few miles it dropped to a level so nearly the same as that of the filling at the succeeding, Wisconsin, stage of glaciation that it cannot well be differentiated. In each the level of filling is about 60 feet above present low water, and 30 to 40 feet above flood stages.

[1] Frank Leverett, "The Illinois Glacial Lobe," *U.S. Geol. Surv.*, Monograph XXXVIII (1899), pp. 89–97, Pl. VI.

It is probable that the aggradation at the Illinoian stage was sufficient to enable the river to make use of a low pass across the rock ridge below Thebes, Illinois, and thus join the Ohio more directly than by the old course. The contours of this new course seem to be about the same as in the Des Moines rapids and those above Rock Island, and thus to favor a similar age.

The Iowan glaciation appears to have been too light and transitory, or to have encroached on the Mississippi Valley too little, to produce any permanent deflections of the stream. It may, however, have reached to the valley both from the east and west in the vicinity of Clinton, as indicated by maps and descriptions in Monograph XXXVIII.[1] There are deposits of sandy gravel along some of the tributaries of the Mississippi in southeastern Minnesota and in western Wisconsin that are outside the glacial drainage lines which were connected with the Wisconsin ice sheet, and which are tentatively referred to the Iowan glacial drainage. The material is nearly as fresh as gravel of Wisconsin age, and its preservation from erosion is but little different from that of Wisconsin deposits. It seems, therefore, to be too young to refer to the Illinoian glacial drainage.

The Wisconsin glaciation covered only the headwaters of the Mississippi down to a point a little below St. Paul. But it covered the lower Illinois, and built great moraines to the north and west of Hennepin that have effectually barred the upper Mississippi from returning to its old course into the lower Illinois Valley.

The glacial drainage into the Mississippi from the Wisconsin drift at first had its head on the outer slope of a moraine that crosses the river in the southeast part of the St. Paul quadrangle. The drainage was extended up the valley step by step with the recession of the ice border. At the border of the Wisconsin drift there is an extensive outwash plain, 940 to 960 feet above sea level, or 260 to 280 feet above the Mississippi River. From this outwash plain there was drainage down the course of the Vermillion Valley as well as down the present Mississippi, with a descent of fully 100 feet in about 20 miles. The filling is a fine, sandy gravel, and

[1] *Op. cit.*, pp. 131–153, Pls. VI and XII.

well records indicate that it was built up from near the level of the present river. At Red Wing the filling is 125 feet above the river, or 790 feet above sea-level. Its slope is more rapid than the fall of the river as far down as the mouth of the Wisconsin River. It is there about 70 feet above the river, or 675 feet A.T. At Bagley, Wisconsin, 12 miles farther down, the filling is only 60 feet above the river, and it maintains a height of 50 to 60 feet above the river from there down to about the mouth of the Ohio River. Just above the Des Moines rapids, in the vicinity of Fort Madison, the Wisconsin filling is exceptionally well preserved at a level 50 to 55 feet above the river.

There were accessions from tributaries at several points, the most important being St. Croix, Chippewa, Wisconsin, Rock and Illinois rivers. The Illinois is likely to have made a contribution of sediment to the lower Mississippi larger than that brought down from the upper Mississippi. The Illinois Valley was built up at the Wisconsin drift border, at Peoria, 170 feet above the present stream. In 175 miles from Peoria to Alton, at the head of the American Bottoms on the Mississippi, there is a descent of about 160 feet in the surface of the sandy filling of Wisconsin age, while the present stream falls only about 25 feet in the same distance. Below St. Louis there is sandy filling, which seems referable to the Wisconsin glacial drainage, in small remnants in recesses of the valley and in the mouths of tributary valleys. Filling of this sort is found as far down as the place where the Mississippi turns into the gorge near Thebes. The new topographic map of the Jonesboro quadrangle brings out terraces at the mouths of Dutch Creek and Clear Creek valleys which catch the 380-foot contour. They are 30 feet above the broad flood plain of the river.

DRAINAGE FROM THE GLACIAL LAKES

The Mississippi Valley was the line of discharge to the Gulf of Mexico for several of the great glacial lakes that were developed in front of the receding ice border. Lake Agassiz, with a maximum area as large as that of all the present Great Laurentian lakes, drained into the Mississippi through the Minnesota Valley; Lake Duluth, in the Superior Basin, drained through the St. Croix

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Valley, and Lake Chicago, in the Michigan Basin, through the Illinois Valley. At times Lake Chicago carried the drainage of glacial lakes in the Huron and Erie basins. As these lakes were settling basins, their outlets carried very little sediment, and the volume of water being large, they cut deeply into deposits that had been

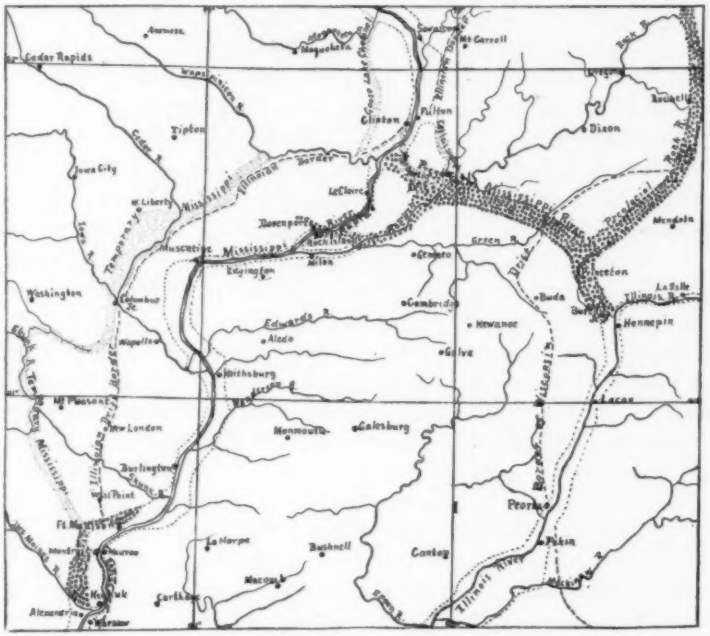

FIG 2.—Map showing shiftings of course of Mississippi River

built up by the waters flowing directly from the ice sheet, and developed a low gradient, lower than is consistent with the present Minnesota, St. Croix, and Illinois rivers, or even with the Mississippi River. At the junction of the Minnesota and the Mississippi it cut to a level 30–40 feet below the present streams, and there is now backwater of that depth in the lower end of the Minnesota Valley, caused by the aggrading effect of the Mississippi River. The conditions are similar at the mouth of the St. Croix

River, and its lower part, below Stillwater, is known as Lake St. Croix. A few miles farther down is Lake Pepin, where for a length of 25 miles the Mississippi is ponded by a barrier built up from sediment brought in by the Chippewa and Zumbro rivers. The level has thus been raised at least 40 feet at the lower end of the lake. There appears to have been aggradation by the present stream along much of the course from Lake Pepin to the head of the rapids below the mouth of the Wapsipinicon.

The channel across these rapids seems to have been inadequate to carry the great volume of water from the glacial lakes, for part of it flowed southward to Rock River through channels now occupied by Meredosia and Cattail sloughs (Fig. 2), and thence down Rock River Valley to the Mississippi below the rapids. Peat deposits now fill these channels to such height that only the highest floods pass through them, but the beds of the channels are about as low as the low-water level of the present river. The rapids thus seem to have been cut down but little since the waters of the glacial lakes ceased flowing over them. The Des Moines rapids, above Keokuk, took the entire flow of the glacial lake waters. The river at the head of the rapids is 50–60 feet lower than the surface of the Wisconsin deposits of sandy gravel immediately above them. It is probable that much of this lowering is due to the waters of the glacial lakes.

The Illinois Valley was cut to a very low gradient by the waters of Lake Chicago. Under present conditions there is a fall of slightly less than 30 feet in the 220 miles below La Salle. But as the mouth of the Illinois is immediately above the mouth of the Missouri the sediment from that stream may have raised the level of the mouth of the Illinois since the waters of Lake Chicago ceased flowing down the Illinois Valley. The amount of aggradation thus produced is a difficult matter to estimate. Possibly it is as great as that below Lake Pepin, some 30 to 40 feet. Attention was directed above to the influence of the sediment of the Missouri on the gradient of the Mississippi below its mouth.

THE PHYSICAL CHEMISTRY OF THE CRYSTALLIZATION AND MAGMATIC DIFFERENTIATION OF IGNEOUS ROCKS

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IV

MAGNETITE

Magnetite and olivine (with fayalite).—As discussed in "Silikatschmelzlösungen," I (1903), the individualization boundary between magnetite and fayalite (reckoned by weight) lies at about:

$$0.2-0.25\ Fe_3O_4 : 0.8-0.75\ Fe_2SiO_4.$$

Near the same boundary, probably with somewhat less magnetite and somewhat more olivine, we find in the "titanomagnetite"-olivinites, chiefly consisting of the so-called "titanomagnetite," which is a mechanical mixture of magnetite and ilmenite, and of olivine, the latter with proportions intermediate between Fe_2SiO_4 and Mg_2SiO_4 (partly stoechiometrically about $0.4\ Fe_2SiO_4 \cdot 0.6\ Mg_2SiO_4$, partly still more Fe_2SiO_4 and less Mg_2SiO_4). As described several years ago by earlier investigators, among them also myself, the olivine in these rocks appears partly porphyric in the "titanomagnetite" when it is quite abundant. As an example we may take the "titanomagnetite"-olivinite from Cumberland in Rhode Island, according to C. H. Warren[1] with an average mineralogical composition of 46.1 per cent olivine ($0.39\ Fe_2SiO_4 \cdot 0.61\ Mg_2SiO_4$), 20.7 magnetite, 18.6 ilmenite, 9.2 labradorite (Ab_3An_4), 3.6 spinel (and in addition a little Or and sulphide).

The specimen at my disposal (Fig. 27) gives the same proportions between olivine and magnetite plus ilmenite, but less labradorite and less spinel. The olivine shows a more or less well-developed idiomorphic contour against the iron-ore minerals.

[1] *Amer. Jour. of Sci.* (1908), p. 175.

A few quite small individuals of magnetite or ilmenite also appear in the olivine.

The sequence of crystallization cannot here be explained in detail, but so much can be said, that the olivine commenced crystallizing at a very early stage, and certainly not much magnetite

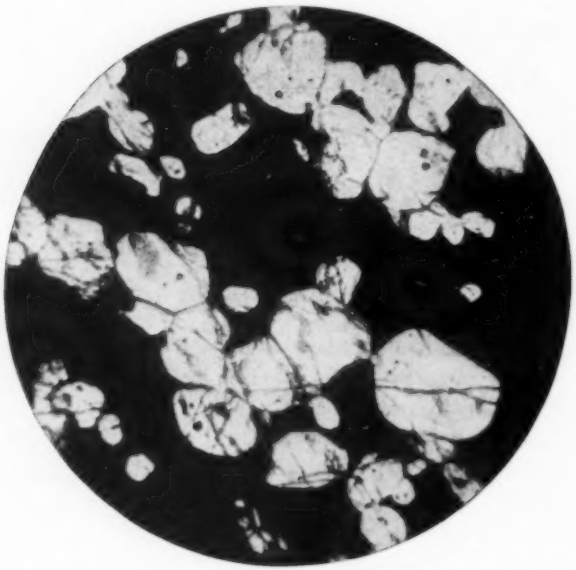

FIG. 27.—Photomicrograph (25:1) of "titanomagnetite"-olivinite from Cumberland, Rhode Island. White = olivine, black = "titanomagnetite."

or ilmenite can have been solidified before the commencement of crystallization of the olivine.

Very interesting in structural respect is a "titanomagnetite"-olivinite (Fig. 28) from Fiskaa in Söndmöre, Norway, consisting of about 50 per cent olivine (according to optical investigations 0.35–0.4 Fe_2SiO_4:0.65–0.6 Mg_2SiO_4); about 40 per cent magnetite plus ilmenite, about 5 per cent spinel; and in addition locally a little hypersthene.

The olivine, with no sign of an idiomorphic contour, shows in nearly every individual an intimate intergrowth with the iron ore,

chiefly magnetite, giving in this manner a form of structure nearly identical with graphic granite or with coarse-grained granophyre. This must be due to a *simultaneous* crystallization of the olivine and the iron ore, especially the magnetite, and the proportion by weight in the intergrown individuals gives about 0.25

FIG. 28.—Photomicrograph (25:1). "Titanomagnetite"-olivinite from Fiskaa, Söndmöre, Norway. White = olivine, black = titanomagnetite. The small gray grains in the photograph are spinel.

magnetite:0.75 olivine, this representing a point or a line on a quite complicated eutectic boundary curve.

Magnetite in gabbro, norite, anorthosite, etc.—As is well known, and still believed by many petrographers, Rosenbusch made the assertion that the oxidic iron ores, magnetite, ilmenite, etc., always belong to the oldest segregations, and crystallized before the solidification of the silicates. This assertion, however, is not correct with regard to the gabbroic rocks, for when only little magnetite (and ilmenite) is present, the crystallization of iron ore does not

commence until the surplus silicate mineral has solidified, so that the quantity of Fe_3O_4 (and $FeTiO_3$) in the rest of the magma has reached a certain amount.

In this connection we choose as an example a rock with a surplus of *plagioclase*. This has previously been described in detail by myself, and treated above, viz., the porphyritic labradorite-norite from Flakstadöen in Lofoten. In proportion to the whole rock 23 per cent labradorite was solidified first, and the crystallization of iron ore, simultaneously with the continued crystallization of plagioclase only commenced when the quantity of iron ore had reached 8.1 per cent Fe_3O_4+0.9 per cent $FeTiO_3$. If we leave out of consideration the components present in small quantity (biotite, apatite, and ilmenite), we obtain the following figures for the commencement of crystallization of the magnetite: about 8.5 per cent magenetite; about 64.5 labradorite; about 13.5 hypersthene; about 13.5 diallage. This represents a point or a line on the individualization boundary between the labradorite and magnetite in a very complicated system, magnetite:labradorite (42 Ab, 6 Or, 52 An):hypersthene:diallage (the two last with many separate components).

In hyperitic-structured gabbro and norite (with olivine gabbro and norite), where at an early stage *much plagioclase* had solidified in the well-known lath-shaped individuals, the magnetite (and ilmenite), when present only in a quantity as small as 1–2 per cent, shows no sign of idiomorphic contour.

On the contrary, the magnetite here only appears as an intervening mass chiefly between the plagioclase individuals (see Figs. 29 and 30), indicating that much plagioclase had already solidified before the magnetite commenced forming.

In this connection we refer to a treatise by S. Foslie (Kristiania) on "The Titanic Iron Ore Deposit at Ramsöy and Its Processes of Differentiation,"[1] where is described a hornblende gabbro, containing about 58 per cent plagioclase, 2.5 per cent magnetite, 31 per cent hornblende, 6.5 per cent biotite, and 2 per cent quartz, with the magnetite formed later than the plagioclase. His photomicrograph, Table I, Figure 1, accords quite well with Figures 29–30 in this paper.

[1] *Geol. Survey of Norway, Aarbog for 1913.*

In the norites, relatively *rich in hypersthene* but quite poor in magnetite (and ilmenite), the crystallization of iron ore did not commence until some part of the hypersthene had solidified. As an example we choose a norite from Skougen in Bamle, which, according to the chemical analysis (see the section on norite in Part II), contains 1.09 per cent TiO_2, 1.44 Fe_2O_3, and 9.42 FeO. The mineralogical composition is about 47 per cent hypersthene (with a little secondary hornblende), 3 per cent biotite, 48 per cent labradorite, and about 1–2 per cent iron ore, and in addition a little

FIG. 29.—Photomicrograph (21:1)

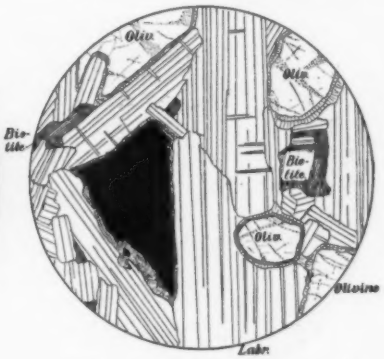

FIG. 30.—Drawing (21:1)

Hyperitic-structured olivine-gabbro from Elverum, Norway. Consisting of *ca.* 65 per cent labradorite, 10 per cent olivine, 10–15 per cent diallage, 3–5 per cent biotite, and *ca.* 2 per cent magnetite (with a little ilmenite).

apatite and pyrite. An essential part of TiO_2 and Fe_2O_3 enters into hypersthene and biotite. In most parts of the thin section (see Fig. 13) iron ore is lacking as it only appears in a few places.[1] Here the hypersthene shows an idiomorphic contour against the magnetite, and this applies especially to the relatively *small* individuals of hypersthene, which partly have an entirely straight crystallographic boundary against the magnetite (with ilmenite).

The latter, on the contrary, shows no signs of idiomorphic outlines. Some part of the hypersthene must thus have solidified before the formation of the magnetite. Since especially the *small*

[1] For this reason we are not able to determine the quantity of the iron ore with precision by a planimeter calculation of the thin section.

individuals of hypersthene show marked idiomorphism against the magnetite (and ilmenite), the crystallization of the iron ore seems to have begun when only the lesser part of the hypersthene had solidified.

Further we find here and there in the same thin section some small crystals of pyrite, surrounded by a thin wreath of magnetite (or "titanomagnetite"). The pyrite accordingly has here served as *Fixkörper* for the deposit of magnetite, which also indicates a solidification of the magnetite at a relatively early stage, while the essential part of the rock still remained in the liquid phase.

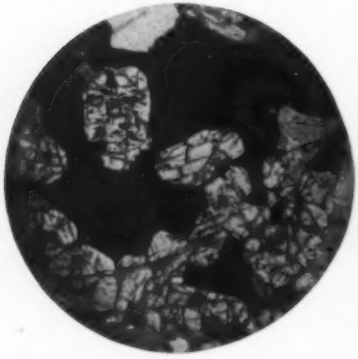

FIG. 31.—Photomicrograph (30:1)

FIG. 32.—Photomicrograph (45:1)

From the same thin section of norite from Skougen shown in Figure 13, containing 1–2 per cent "titanomagnetite." Figures 31 and 32 represent two places with much magnetite (and ilmenite), besides hypersthene, a little hornblende, and biotite.

In the olivine-hyperites, *rich in olivine*, with about 25–30 per cent olivine, only 1–2 per cent "titanomagnetite," much plagioclase (labradorite, quite rich in An), and some diallage, etc., the crystallization, as mentioned above, commenced with the solidification of some olivine, and only then did the "titanomagnetite" commence crystallizing as a deposit on the olivine crystals which acted as a *Fixkörper*. We refer to Figure 33, drawn with the detailed help of a photomicrograph.

We have here treated several gabbros and norites with only *very little* magnetite (and ilmenite). In the corresponding rocks

with a somewhat *larger quantity* of magnetite (and ilmenite) the sequence of crystallization, on the contrary, is different. Here we find idiomorphic crystals, especially octahedrons of magnetite, appearing in the silicate minerals first crystallized. In gabbroidic rocks with much hypersthene, diallage, or olivine, the magnetite seems already to have commenced its crystallization at about 4 per cent Fe_3O_4, and about simultaneously with the first individualized

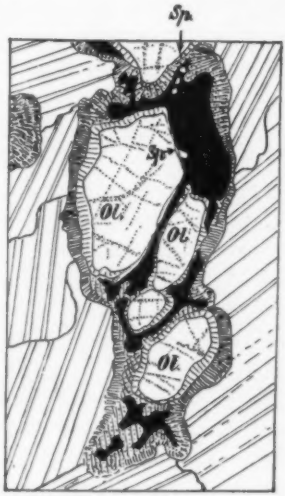

FIG. 33.—Hyperitic-structured olivine-gabbro from Langö, near Kragerö, Norway. Contains about 25 per cent olivine (Ol.), *ca.* 1–2 per cent magnetite with ilmenite (black), 60 per cent labradorite, 12 per cent diallage, 2 per cent brown hornblende, 0.01–0.02 per cent spinel (Sp.) in the magnetite, very little apatite. Drawn partly from photograph and partly from nature.

Magnetite (with ilmenite), younger than the olivine. Olivine with reaction rims against the labradorite. (In the inner zone hypersthene, in the exterior zone green hornblende and spinel.) Between the magnetite and the labradorite is a reaction rim consisting chiefly of light-brown hornblende. (28:1.)

ferromagnesian silicate. This boundary, 4 per cent Fe_3O_4, is, however, quite approximate, and it is to a great extent dependent upon the composition of the magma.

In gabbro rocks, rich in plagioclase, and in anorthosite gabbros, the boundary seems to lie somewhat higher, viz., according to

my earlier determination of the rock from Lofoten described above, at about 8–9 per cent magnetite.[1]

We here interject the remark that the simultaneous crystallization of "titanomagnetite" and hypersthene, diallage, or olivine, taking place at an early stage of crystallization in norites and gabbros (with olivine gabbros, etc.) which carry much ferromagnesian silicate and some few per cent of iron ore, explains how the well-known magmatic differentiation products of "titanomagnetite" in these rocks are characterized by an enrichment of "titanomagnetite" plus the ferromagnesian silicate in question, consequently hypersthene, diallage, or olivine respectively.

Magnetite in the granitic rocks.—Here the magnetite, when present in a quantity of at least 0.5 or 1 per cent, commences crystallizing at a very early stage, viz., a little later than the apatite, which, as is known, often appears as idiomorphic needles in the magnetite, but on the other hand earlier than the biotite or other ferromagnesian silicates which, in part, were deposited on the *Fixkörper* magnetite.

At this early stage, however, the whole quantity of magnetite was not crystallized. We are thus able to detect exceedingly small magnetite individuals in the groundmass, for example, in quartz porphyres; and the many analyses (Nos. 14*c*–29*c*) of glass, ground-mass, and intervening mass between the orbicules, etc., in granite without exception show a little Fe_2O_3 and FeO. In the granitic eutectic which at last results, there usually seems to appear about 1 per cent Fe_2O_3 and FeO, of which, however, a little is bound up with the small quantity of ferromagnesian silicate, and a little Fe_2O_3 probably also appears as a solid solution in the feldspar. The magnetite seems to appear in the final eutectic in a quantity of about 0.5 per cent.

For the magnetite as well as for the ferromagnesian silicates the solubility is much less in the granitic than in the gabbroidic magmas.

Spinel.—Magnetite and spinel (pleonast and hercynite) (Mg, Fe) $(Al_2, Fe_2)O_4$, with at most about 7–10 per cent Fe_2O_3, but sometimes with more FeO than MgO, form between them *a* series of

[1] Foslie (*loc. cit.*) sets the boundary still somewhat higher. This, however, is not in accordance with my investigations of the problem in hand.

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discontinuous mix-crystals with a eutectic boundary consisting of about 2.5–3 per cent spinel:97.5–97 per cent magnetite (cf. my treatise, cited p. 2, "Über das Spinell:Magnetit-Eutektikum," 1910).

In the igneous rocks, containing *primary* spinel, this mineral, as is well known, belongs to the very first stage of crystallization when it is present in at least about 0.1 per cent by weight. But if the quantity of spinel sinks still lower the case is different. As an example we may mention that in the olivine-hyperite, illustrated in Figure 33, where first some olivine crystallized and later a little magnetite, some quite small individuals of spinel often appear in the magnetite. The spinel forms about 1 per cent of the magnetite, and since the latter forms 1–2 per cent of the entire rock, the quantity of spinel may consequently be set to 0.01–0.02 per cent. And this minimal quantity of spinel did not crystallize until mineral No. 1, in this case the olivine, had commenced forming.

Further we shall mention an ilmenite-norite from Storgangen near Soggendal (Ekersund), consisting of about 40 per cent ilmenite, 40 per cent hypersthene, 20 per cent labradorite, and in addition 1–2 per cent biotite, about 0.2 per cent pyrite, and about 0.1 per cent spinel. The latter is intensely green and must be termed hercynite.

The pyrite appears in small cubes (with edges 0.1–0.3 mm.) and on these quite small spinels (0.04–0.1 mm. large) have grown. These were deposited on the crystals of pyrite,[1] which in this manner served as *Fixkörper* in the still molten magma. The small spinels show an octahedron boundary against the surrounding, later mineral—ilmenite, labradorite, or hypersthene. FeS_2 as well as (Mg, Fe) $(Al_2, Fe_2)O_4$ were so little soluble in this magma that, although present in so small a quantity, they commenced crystallizing at an earlier stage than the silicates and the iron ore, but in such a manner that at the very first stage some pyrite solidified, and then, at somewhat lower temperature, the spinel.

The essential part of the *apatite* crystallizes, as is well known, at a very early stage. Sometimes, in the same thin section (Fig. 35), we may find a crystal of pyrite serving as *Fixkörper* for the deposit

[1] The same sequence of crystallization, spinel later than pyrite, I have mentioned also in an earlier treatise, see *Zeitschr. f. prakt. Geol.* (1900), p. 238, Fig. 39.

of apatite, and in other places a crystal of apatite serving as *Fixkörper* for a deposit of pyrite, showing that the two minerals were formed practically simultaneously. At the same weight (as 0.1–0.25 per cent) of apatite, pyrite, and spinel, the crystallization of apatite and pyrite seems to commence at a somewhat earlier stage than the crystallization of spinel.

FIG. 34.—From an ilmenite-norite from Storgangen, near Soggendal, Norway. Three crystals of pyrite on which have been deposited small crystals of spinel, lying in ilmenite. (40:1.)

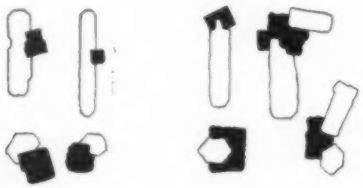

FIG. 35.—From a uralitic quartz-norite from Flaad, Evje, Norway. Black = pyrite, white = apatite. (40:1.)

PYRITE AND PYRRHOTITE

According to the precision-investigations by E. T. Allen, I. L. Crenshaw, and I. Johnson,[1] at the Geophysical Laboratory in Washington, the melting-points are for FeS, 1170 ± 5°; for pyrrhotite, 1183° (to 1187°).

The analyses of phyrrhotite show, as is well known, a surplus of S above the proportion Fe:S, which the investigators mentioned (1912) interpreted to indicate that some S entered as a solid solution in FeS. Soon after, Docent C. W. Carstens,[2] of Trondhjem, pointed out that what enters in the solid solution must be FeS_2 and not S, an interpretation which, independently of Carstens' statement,

[1] *Amer. Jour. of Sci.*, Vol. XXXIII (1912).

[2] *Norsk geologisk tidsskrift*, Vol. III (1914).

was also later indicated by Posnjak, Allen, and Mervin[1] at the Laboratory in Washington.

That this is really so, appears theoretically through the fact that the process:

$$FeS+S \gtrless FeS_2$$

is reversible. FeS in solid solution is able to absorb as much as 23 per cent FeS_2. The solubility of FeS in FeS_2 is, however, nil or minimal.

For the discontinuous binary mix-crystal system, only two cases exist, viz., either type V (with a eutectic) or type IV (with a bending-point). By the following observations we may determine to which of these two types the system $FeS:FeS_2$ belongs.

1. The pyrrhotite has a relatively low melting-point not only at the pressure of one atmosphere but, as appears from the statement given below, also at the high pressures prevailing in deep-seated magmas. The pyrite, on the other hand, crystallized in the deep-seated magmas at a very early stage and, consequently, at a relatively high temperature. The pyrite, accordingly, at high pressure may exist in the solid phase at a much higher temperature than the melting-point of the pyrrhotite. The genesis of the intrusive pyrite deposits proves that FeS_2 at very high pressure may also occur in the liquid phase. Pyrite consequently (at high pressure) has an even much higher melting-point than pyrrhotite.

2. Pyrrhotite (FeS with FeS_2 in solid solution, with as much as 23 per cent FeS_2:77 per cent FeS) has a higher melting-point (*G* on Fig. 36) than FeS. This already proves that the system belongs to type IV.[2]

3. We have a confirmation of this in the fact that in the ore deposits of pyrite and pyrrhotite, formed by magmatic differentiation, we always find, irrespective of the proportion by weight between the two sulphides, the sequence of crystallization, (1) pyrite (2) pyrrhotite, but, on the other hand, never the inverse sequence of crystallization, (1) pyrrhotite, and (2) pyrites. Regarding the

[1] *Amer. Jour. of Sci.*, Vol. XXXVI (1915).

[2] See my résumé-treatise, "Die Sulfid-Silikatschmelzlösungen" (1917).

resorption phenomena at the stage I to K we refer to the explanation in a later paragraph.

With regard to the structure of the deposits of *pyrrhotite-hypersthenites*, *-olivinites*, *-norites*, etc., formed by magmatic differentiation, I refer to my earlier publication "Die Sulfid-Silikatschmelzlösungen" (in *Norsk geologisk tidsskrift*, 1917). I shall here only give a short summary.

We shall commence with the per se very rare *pyrrhotite-olivinites*, and as an example choose the deposit at Bruvand (Ballangen,

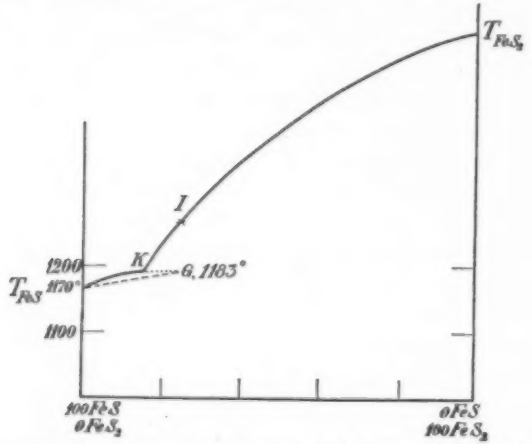

FIG. 36.—The binary system FeS: FeS, at high pressure. (The melting-points for FeS and pyrrhotite refer to low pressure.)

Ofoten in Norway) where the olivinite carries about 8 per cent sulphides, which we for brevity's sake shall term "nickel-pyrrhotite" (pyrrhotite with some pentlandite, chalcopyrite, and pyrite, in the present case with about 6–7 per cent nickel).

The rock consists, with deduction of the sulphides, of about 85–90 per cent olivine (according to chemical analysis 0.12 Fe_2SiO_4·0.88 Mg_2SiO_4, and accordingly quite poor in iron and not the least serpentinized), and in addition a little bronzite, primary hornblende, etc. The sulphides are not quite evenly distributed over the whole rock, but accumulated in small patches, especially on the boundary between the olivine grains (see Fig. 37).

This is most clearly shown in the thin sections (see Figs. 38 and 39), where the olivine individuals against the pyrrhotite show more or less well-developed idiomorphism; however, such that the edges are somewhat rounded.

We especially remark the quite good idiomorphism of the *small* olivine individuals against the pyrrhotite.

The rather common segregations of *pyrrhotite-hypersthenite* in hypersthene-rich norites carry from 10–20 to 50–60 per cent of nickel-pyrrhotite. Besides the sulphides, they may carry hypersthene alone or hypersthene accompanied by more or less plagioclase, etc. The hypersthene here appears as porphyritic crystals in the pyrrhotite; the boundary planes of the crystals, however, usually are somewhat rounded, with small bends, etc. (see Figs. 40–43).

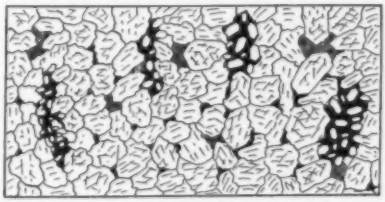

FIG. 37.—Pyrrhotite-olivinite from Bruvand, Ofoten, Norway. Light-structured mineral = olivine, dark-structured = bronzite and hornblende, black = pyrrhotite. (Natural size.)

A corresponding structure may also be observed in a *pyrrhotite-norite* from Dyrhaug in Værdalen, chiefly consisting of labradorite (Ab_1An_2, occasionally with zonal structure from about $Ab_{28}An_{72}$ in the kernel to about $Ab_{40}An_{60}$ in the exterior zone) and nickel-pyrrhotite (see Figs. 44, 45).

The structure here described can only be explained to show that the *olivine* (Figs. 37–39), the *hypersthene* (Figs. 40–43), and the *labradorite* (Figs. 44–45) *have crystallized at an earlier stage than the nickel-pyrrhotite.*

And this is in best conformity with the intervals of the melting-points, calculated for the different minerals at atmospheric pressure, and only quite unessentially changed at higher pressure (see a following paragraph).

The melting-point of pyrrhotite is 1183° (or 1187°), and for a sulphide mixture, consisting of predominant pyrrhotite, 3–6 per cent pyrite, some chalcopyrites, and some pentlandite, we may fix the crystallization interval from about 1190° (or about 1200°), for the commencement of crystallization of the pyrite, down to,

or perhaps a little below 1150° for the last remnant of sulphides, consisting of chalcopyrite with some pyrrhotite and some pentlandite.

FIG. 38.—Photomicrograph between crossed nicols (15:1).

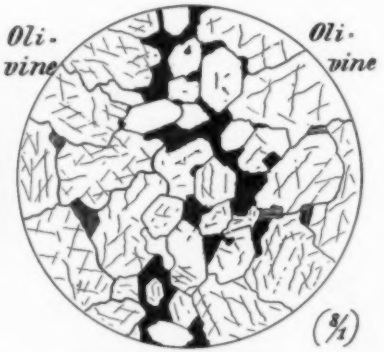

FIG. 39.—Drawing (8:1)

Pyrrhotite-olivinite from Bruvand (cf. Fig. 37). Two different portions.

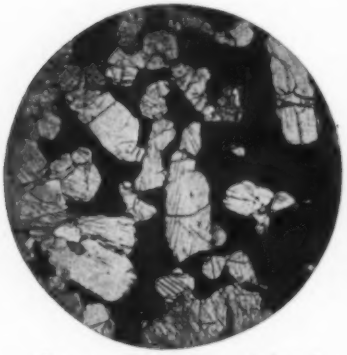

FIG. 40.—Photomicrograph (17:1)

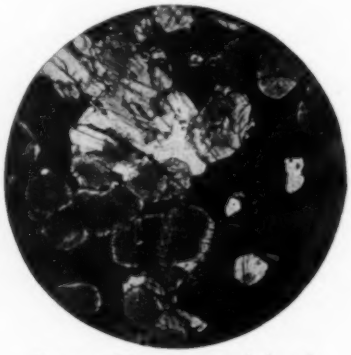

FIG. 41.—Photomicrograph (17:1)

Pyrrhotite-hypersthenite from Romsaas (Fig. 40) and Messel, near Arendal (Fig. 41). In Figure 40 besides pyrrhotite there is only hypersthene. In Figure 41 besides hypersthene there is also a little labradorite (upper left). In Figure 41 two small holes in the thin section appear white.

For an olivinite, consisting of predominant olivine (0.12 Fe_2SiO_4·0.88 Mg_2SiO_4) and a little orthorhombic pyroxene

(bronzite), likewise quite iron-poor, and iron-poor hornblende, we may reckon a crystallization interval from about 1500° down to 1400° or somewhat lower.

For hypersthene (with about $0.3FeSiO_3 \cdot 0.7\ MgSiO_3$) the crystallization interval, according to the earlier approximate determinations, lies at about 1300–1200°.

In a silicate mixture, consisting of predominant labradorite (Ab_1An_2) and a little diallage and hypersthene, the labradorite

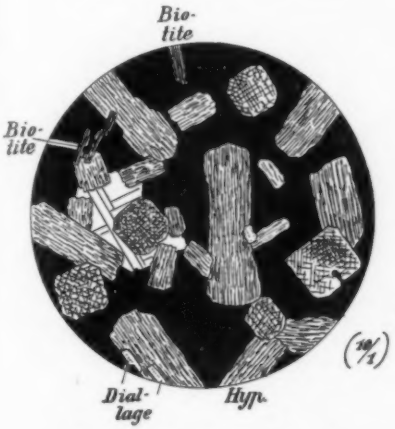

FIG. 42.—From Romsaas (10:1)

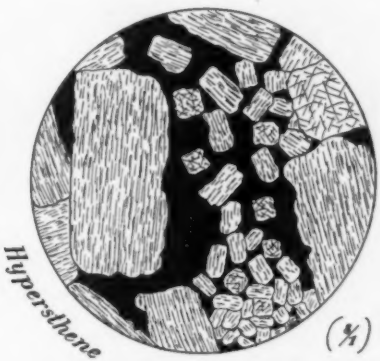

FIG. 43.—From Messel (8:1)

Drawings of pyrrhotite-hypersthenite. In Figure 42 besides hypersthene there is a crystal of labradorite (with twinning lamellae), a little biotite, and traces of diallage.

will commence crystallizing at about 1450°, and the essential part of the rock will be solidified at about 1300–1250°. The residual magma, present in quite small quantity, will crystallize along a eutectic boundary-line, down to about 1200° or probably a trifle lower. For the three pyrrhotite rocks just mentioned, the silicates must consequently in two cases have crystallized entirely and in the third case either entirely, or nearly entirely, while the sulphides were still in the liquid phase.

At temperatures of 1500°, 1400°, and 1300° melted silicate of the composition of olivinite, hypersthenite, or labradorite-rich

norite, may contain in solution only quite a small quantity of FeS (and still less of Cu_2S and NiS). Melted sulphide, consisting of FeS, etc., may, at the temperatures mentioned, dissolve only a trifle silicate.[1] The pyrrhotite-rich rocks mentioned must therefore during the interval of crystallization have consisted of *two liquids* (*two liquid phases*), *one silicate phase* with only a little dissolved sulphide and *one sulphide phase* without or with only a very inconsiderable amount of dissolved silicate.

FIG. 44.—Photomicrograph between crossed nicols (15:1).

FIG. 45.—Drawing (8:1)

Pyrrhotite-norite from Dyrhaug, Skjækerdalen, Værdalen, Norway (cf. Figs. 20 and 21). Porphyritic labradorite in nickel-pyrrhotite, besides a little hypersthene, diallage, and biotite.

The common norites and gabbros usually contain 0.1–0.4 per cent S, which corresponds to about 0.25–1 per cent pyrrhotite, which, however, occasionally is accompanied by some pyrites. The pyrrhotite is here usually not evenly distributed in quite small individuals over the whole rock, but most often accumulated in somewhat larger lumps with a diameter of 0.5, 1, or 2 mm., occasionally more (see, for instance, Fig. 10).

Against the pyrrhotite the hypersthene as well as the diallage and labradorite here also appear with idiomorphic outlines. As an example we refer to Figures 12 and 21 and to Figure 46 from a

[1] See "Sulfid: Silikatschmelzlösungen," I (1919).

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norite from Erteli, Norway, which, according to the analysis of the entire specimen, only contains 0.07 per cent S=0.18 per cent pyrrhotite, here and there accumulated in small lumps.

For the photomicrograph was chosen a locally pyrrhotite-rich part of the thin section, otherwise free from pyrrhotite. That pyrrhotite also crystallized last in common norites and gabbros is due to the circumstance that the intervals of the crystallization

FIG. 46

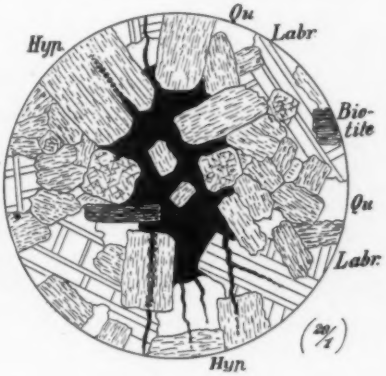

FIG. 47

FIG. 46.—Photomicrograph between crossed nicols (15:1). Pyrrhotite in norite from Erteli, from the same thin section as Figures 15 and 16. The rock contains 0.07 per cent S. Figure 46 is from a portion rich in pyrrhotite.

FIG. 47.—Quartz-norite from Romsaas, Norway (20:1). Illustrating a portion rich in pyrrhotite, from the same thin section as Figure 10. The hypersthene, biotite, and labradorite show idiomorphic contours against the pyrrhotite, and small veins of pyrrhotite cross the silicates.

for the silicates lay somewhat above, but for the pyrrhotite a little below, 1200°.

As well in pyrrhotite-hypersthenites and -norites, etc. with quite much pyrrhotite, as in the common norites, etc. with only about 0.2–0.5 or 1 per cent pyrrhotite, we frequently find *veins of pyrrhotite* branching off from relatively larger accumulations of this mineral, and intersecting the neighboring minerals.

We refer to Figure 47, where we see quite thin veins of pyrrhotite intersecting the hypersthene and the labradorite, which otherwise

show idiomorphic contours against the pyrrhotite. This phenomenon is due to the fact that the melted FeS even at *so low a temperature* as about 1200° is very thin fluid.[1]

FeS_2 is so little soluble in the silicate magma that the limit of the solubility, when only about 0.1–0.2 per cent FeS_2 is present, is usually reached by the cooling of the magma to somewhat above the upper boundary of the crystallization interval of the silicates. The melting-point of FeS_2 lies (at high pressure) at a still higher temperature. FeS_2 consequently, in the common igneous rocks, separates in the *solid* phase.

The solubility of *FeS* in silicate magmas at any temperature depends, as explained in my treatise "Die Sulfid-Silikatschmelzlösungen," on the chemical composition of the magma; the solubility under otherwise similar conditions increasing with the basicity. And as usual with dissolved substances, the solubility of FeS also increases with the temperature. In melts of gabbroidic composition, the solubility at 1350–1400° and at the pressure of one atmosphere is about 0.25–0.4 per cent FeS but decreases rapidly at a little lower temperature, as about 1300°. When the limit of solubility is reached by the cooling of the silicate magma, FeS accordingly separates in the *liquid* phase.

On account of the great difference existing at high pressure between the melting-points of FeS_2 and FeS, an essential difference arises with regard to the physics of the segregation: *FeS_2 crystallizes while FeS, on the other hand, separates in liquid phase* and remains in this condition till near the termination of the solidification of the rock.

The *intrusive deposits of pyrite*, which often are characterized by nearly exclusively pyrite, and which usually do not contain any pyrrhotite, prove also that FeS_2 at especially high pressure may exist in the liquid phase.

The formation of these deposits is probably due to the fact that locally in the igneous magmas so much FeS_2 has been present, that the latter at especially *high* temperature has been secreted at

[1] See "Die Sulfid-Silikatschmelzlösungen" (1917), where I have discussed the importance of the thinness of the pyrrhotite magma for the interpretation of the morphology of these deposits.

a stage above its melting-point, accordingly in the liquid phase. But the rocks normally contain so little FeS_2 that in the granites, syenites, etc., it does not secrete until below the melting-point of the mineral, consequently directly in the solid phase.

ON THE EARLY CRYSTALLIZATION OF "APATITE AND ORES"—OR OF THE "TELECHEMIC" MINERALS

All *phosphates* (apatite and monazite with zenotime in granite-pegmatite dikes), *sulphides* (pyrite, pyrrhotite, chalcopyrite, pentlandite, etc.), *zircon*, *corundum*, *spinel*, *chromite* (in peridotites), *hematite* (and ilmenite and magnetite in the acid igneous rocks), *titanates*, *tantalates*, and *niobates* (the last ones in granite-pegmatite dikes), further *carbon* (graphite, diamond) and native *metals* (nickel-iron, platinum), as is well known, belong to the very first products of crystallization[1] in the igneous rocks. All these substances occupy an exceptional position, being extremely little soluble in silicate magmas at a temperature somewhat above the beginning of crystallization of the silicates, and this independent of their melting-points (very high in corundum and spinel; medium-high for instance in fluorine-apatite, about 1650°; chlorine-apatite, about 1530°; hematite, about 1560°; and probably somewhat lower for instance in titanite, and for pyrrhotite only 1183°).

For all these *early crystallizing* minerals, which in *chemical respect diverge very considerably from the composition of the silicates*, I have in "Die Sulfid-Silikatschmelzlösungen" proposed the term "*telechemic*" minerals (τῆλε, *tele*=distant, the same root as in telegram, telephone, telepathy, etc.).

ON "REACTION RIMS"

We choose for an example the *coronation of olivine* bordering on plagioclase, described from oliviniferous gabbros, etc., by several earlier investigators, with an *inner* zone (adjoining the olivine) consisting of hypersthene, and an *outer* zone (adjoining the plagioclase) consisting of hornblende almost always associated with some amount of spinel. In addition there occurs exceptionally a third

[1] For the pyrrhotite we must change the term crystallization to segregation (to a special fluid phase).

zone, mainly consisting of garnet, immediately adjoining the plagioclase.

1. As is well known, these zones only occur on the boundary between the olivine and the plagioclase, but never between the olivine and the pyroxenes or the magnetite.

2. The zones occur not only in rocks rich in olivine in which the olivine has in a great measure crystallized earlier than the plagioclase (see, for instance, Fig. 27), but also in rocks deficient in olivine where the plagioclase, showing idiomorphic outlines against the olivine, must have crystallized earlier than the latter. I beg to refer to Figures 48–49, representing an olivine-hyperite from Elverum, Norway, consisting of *ca.* 65 per cent labradorite, *ca.* 10 per cent olivine, and *ca.* 25 per cent diallage, the labradorite having early crystallized in lath-shaped crystals, often projecting into the olivine which did not begin to form till a somewhat later stage. We fix on the fact that the coronation zones sometimes branch a little into the labradorite, in part following local transverse fissures, in part twin lamellae, and in part the boundary between various individuals of plagioclase. I further refer to the oliviniferous labradorite rock (with Ab_1An_1) illustrated by Figures 23–24, in which however, the coronation zones are so thin that they are not recognizable in the photomicrograph. High magnifying powers are here required to enable a close examination.

From the very fact that the coronation zones only occur between the olivine and the plagioclase, and are never found between the olivine and other minerals (diallage, hypersthene, etc.), it may be inferred that in rocks rich in olivine the metamorphosis (*Umbildung*) of the olivine did not take place at a conjuncture when only the olivine had crystallized while the rest were still in a molten state. The metamorphosis accordingly, as has been earlier pointed out, particularly by Frank D. Adams, must be a phenomenon belonging to the solid phase. This theory, moreover, is verified by the occurrence of the metamorphism of the olivine as well as of the plagioclase, attached to the *boundary plan* between the two minerals, not only where the olivine is to a great extent crystallized earlier than the plagioclase, but also where the plagioclase to a great extent crystallized earlier than the olivine.

3. The coronation occurs in rocks not dynamometamorphosed, and accordingly, as has been pointed out by earlier investigators, it is no function of any orogenic pressure.

4. The zones here treated I have observed in all of the very many microscopic thin sections that I have examined, of oliviniferous gabbros, norites, and anorthosites (with labradorite or still more basic plagioclase). In fact, the occurrence of the zones in these deep-seated rocks must be accepted as a general phenomenon.

FIG. 48.—Photomicrograph (24:1)

FIG. 49.—Drawing (24:1)

Hyperitic-structured olivine-gabbro from Elverum, Norway. Consists of *ca.* 65 per cent labradorite, 25 per cent diallage, 10 per cent olivine, traces of pyrite (in small cubes in the upper left portion of drawing). The labradorite laths show partial idiomorphism against the olivine (Ol.). Reactions rims between the olivine and the labradorite but not between the olivine and the diallage or between the labradorite and the diallage.

5. The thickness of the zones increases in the deep-seated rocks, as a general rule, proportionately to the amount of An contained in the plagioclase.

I cite: In the oliviniferous labradorite rock (Figs. 23–24) just mentioned (with Ab_1An_1) the total thickness of the zones regularly amounts to only 0.002 mm., sometimes to 0.005–0.010 mm., and exceptionally reaches 0.015 mm. In most olivine-hyperites (with plagioclase about Ab_1An_2), the thickness, as a general rule, is nowhere less than 0.06–0.08 mm.; most frequently it amounts to

0.10–0.12 mm., sometimes it reaches 0.15–0.20 mm., and quite exceptionally even rises to about 0.3–0.4 mm. In oliviniferous rocks with bytownite, the thickness increases to a still larger amount, and exceptionally, in deep-seated rocks containing much basic plagioclase, the whole quantity of olivine may even be spent in forming the zones.

6. The total chemical composition of the zones is equivalent to the chemical composition of olivine plus plagioclase.

It should be particularly emphasized that the zone next the olivine consists of hypersthene, which may be chemically considered as olivine less half the contents of $MgO+FeO$, whereas the zone next the plagioclase consists of hornblende to which in most cases is added some spinel, which may be accounted for by the composition of the plagioclase with some addition of $MgO+FeO$.

The coronation of the olivine against the plagioclase—or, as it may be quite properly expressed as well, the coronation of the plagioclase against the olivine—is a phenomenon belonging to *the solid phase of the minerals after finished crystallization*. My son, Th. Vogt, state geologist, has pointed out to me that to these contact-new-formations the common physicochemical laws concerning the *reaction between two solid phases* are fully applicable.[1]

This reaction is advanced by *high temperature*, and besides is a function of *time*. Therefore it must be assumed that the coronation began to take place immediately after the formation of the two minerals reacting on each other, and went on down to a certain limit of temperature (by way of example, 900°, 700°, 600°, or perhaps lower). The more slowly the cooling took place during the interval of reaction, the more the reaction was intensified. We accordingly always meet with reaction rims between olivine and basic or intermediate plagioclase in deep-seated rocks, but not—or to a much less degree—in the dike and effusive rocks which were more quickly cooled.

[1] See Beyschlag-Krusch-Vogt, *Erzlagerstättenkunde*, Vol. I (2d ed., 1914), p. 122. I beg to point out that the physicochemical laws for the reaction in the solid phase will no doubt throw quite a new light on numerous geologic processes, particularly on dynamometamorphism and contact-metamorphism. Upon these processes the influence of the varying relations of time, pressure, and temperature will particularly be felt.

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The substances most easily soluble in acids generally have the greatest power of reaction. Therefore it is obvious that, as a general rule, the reaction rims should increase according to the amount of An contained in the plagioclase, as the solubility in acids of the plagioclase increases with its contents of An—and in plagioclase more basic than Ab_1An_1 the solubility increases obviously. Both olivine and basic plagioclase are much more easily soluble in acids than, for instance, the pyroxenes, the hornblendes, the micas, or the acid plagioclases. It is therefore easily accounted for that just between olivine and *basic* plagioclase the reaction rims are generally most strongly emphasized.

The general view here maintained of the reaction in the solid phase between olivine and plagioclase may in principle be transferred also on the corresponding reaction rims between diallage and basic plagioclase, between magnetite or titanomagnetite and plagioclase, etc.

[*To be continued*]

SUGGESTIONS AS TO THE DESCRIPTION AND NAMING OF SEDIMENTARY ROCKS

A. J. TIEJE
University of Colorado

It seems unnecessary to apologize for suggestions as to describing and naming sedimentary rocks.[1] Shaw has recently said:

> The need of carefully recorded descriptions of the physical characteristics of ancient sediments is especially worthy of emphasis. . . . . Notwithstanding the fact that advances have been made, there is as yet no adequate systematic classification that is generally acceptable. There is not even a satisfactory nomenclature.

To attempt a thoroughgoing logical classification of sedimentary rocks is beyond the scope of this article. Unless Grabau's compounding of prefixes into one dinosaurian term is deemed objectionable, his classification can scarcely be bettered. Here only two lines of suggestion are offered. One aims at systematizing field descriptions of rocks. The other deals with problems of nomenclature which chiefly arose during the writer's examination of three hundred specimens and eighty thin sections of the so-called "Deadwood" formation in the Bighorn Mountains, Wyoming.

FIELD DESCRIPTION OF SEDIMENTARY ROCKS

Lahee, in a warning against the padding of rock descriptions, remarks that every detail not germane to the immediate purpose of a given report should be omitted.[2] Were reports used only by persons interested in such immediate purposes, the comment would hold good. But if one tries to discuss the conditions of sedimentation in any given region, he is either forced to personal reconnoissance of adjacent regions or to dependence upon published reports of those regions. For such purposes the average descriptions of sediments are lamentably inadequate. Accordingly, there is here

[1] This article was written in April, 1920.

[2] F. H. Lahee, *Field Geology*, p. 450.

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advocated a list of points in the description of sedimentary rocks which, it is believed, should never be omitted.

The list is as follows:

1. *Location.*—Nothing is more provocative of time-wasting than for a second observer to search for a vertical section made "on Wolf or Cow Creek," said creek being in a narrow canyon, 15 miles long. Various more accurate modes of statement readily suggest themselves.

2. *Name of rock.*—This, a matter determinable partly in the field, partly in the laboratory, is later discussed.

3. *Massiveness or stratification.*—This should include mention of the average thickness of beds; or, if there are alternations, reference to average thickness for each type.

4. *Color, fresh and weathered.*—Names for color naturally involve a personal equation. Simplicity is often needed. Admirable as are the descriptions of sediments in such a professional paper as No. 78, the amount of space devoted to refinements of color might well have been allotted to other details. Too often the color of pebbles in a conglomerate is not considered apart from the color of the matrix; secondary color, whether of pebbles or cement, is not distinguished from primary, etc.

5. *Hardness.*—The employment of a mathematical scale, as with minerals, seems impossible. Hardness, however, is usually a result of cementation. The following terms are perhaps usable: (*a*) soft: rock easily broken between the fingers; (*b*) subhard: rock breakable by a light hammer tap; (*c*) hard: rock broken only by a sharp hammer blow; (*d*) superhard: rock dense and resistant to the hammer. Doubtless, strength of arm is here a factor; but the personal equation is less than with color.

6. *Size of grain.*—In the field, measurements can rarely be made. Accordingly, exact limits for such terms as fine-grained, medium-grained, coarse-grained are not advocated. However, the term "pebble" should denote only material over a given size, say $\frac{1}{4}$ in. in diameter. The most inexpert assistant knows such terms as oölitic, pisolitic, etc.

7. *Mineral composition.*—In the field, statement of mineral composition is seldom more than a guess. The use of proper

qualifying adjectives, however, and attention to the order of their arrangement, would be valuable. Arenaceous glauconitic limestone should not be used when glauconitic arenaceous limestone is meant.

8. *Luster.*—Only occasionally does one find such remarks as "vitreous sediments," "clayey surface," etc. Perhaps luster has no great significance. Yet might not freshly exposed rocks be said to have vitreous, subvitreous, dull, earthy, etc., luster?

9. *Lateral variation.*—The importance of this factor can hardly be overemphasized. Any complete description of the "Fountain conglomerate" of the Front Range, e.g., would at once raise doubt as to the ordinary explanation of its origin.

It will be at once remarked that none of these characters throws so much light on the history of a formation as does, say, the mere mention of drying-cracks.[1] May that not be because drying-cracks have been studied by a geologic genius? The trouble with our field descriptions is that we incline to note only the unusual. Moreover, the extension of the writer's list to include drying-cracks, ripple marks, jointing, topographic result of erosion, and other matters, would defeat his very practical aim. An elaborate schedule cannot be recalled in all its ramifications. The simple list here advocated can be easily mastered.

THE NAMING OF SEDIMENTARY ROCKS IN GENERAL

As stated, no attempt is made to present a complete classification of sedimentary rocks. It seems possible, however, to group all sedimentary rocks as follows, partly by the aid of field observations, partly by microscopic examination:

A. ORGANIC—
1. Calcareous rocks
2. Ferruginous rocks
3. Siliceous rocks
4. Carbonaceous rocks
5. Rarer types

[1] There is a further educational value in detailed, systematic description. In courses in advanced general geology, students are often required to make vertical sections based on folios, etc., and even to describe formations in class. If descriptions are so meager that students cannot visualize the sections they describe or construct, is not the value of such work greatly vitiated?

B. INORGANIC—
1. Of chemical origin
   a) Calcareous rocks
   b) Ferruginous rocks
   c) Siliceous rocks
   d) Halides
   e) Sulphates
   f) Rarer types
2. Of mechanical origin
   a) Uncemented
   b) Cemented

It is highly doubtful whether new names under all these headings are needed. Whoever is not enamored of the emptiness of Hegelian dichotomy and its dread of intercrossing rubrics will rest satisfied with the use under A of such stand-bys as bacterial limonite (A 2), diatomaceous earth (A 3), or coal (A 4). Like granite, diorite, gabbro, these names mean something to the geologist who cannot be forever searching his Greek or Latin lexicon for prefixes and suffixes. Nor can any inventor of systems hope to force aside such terms as travertine (B 1*a*), clay ironstone (B 1*b*), novaculite (B 1*c*), salt (B 1*d*), gypsum (B 1*e*).

THE NAMING OF ROCKS UNDER A 1 AND B 2

Obviously, if such familiar names as onyx, sinter, uintaite gypsum are not readily replaceable, there must be a deeper reason even than their establishment in usage. The analysis of this reason results, it is believed, in the discovery that, preponderantly, such names have three great values: (1) they are simple; (2) they aid clear visualization; (3) they suggest a dominant mode of origin. Dissatisfaction with such terms as limestone and sandstone probably arises, it may be unconsciously, from the failure of these names to meet the two latter criteria.

Does not, then, the renaming of organic calcareous rocks and of "clastics" involve, as its pivotal motive, the use of a terminology which shall at least approach the suggestiveness of "coal," "tripoli," etc.? Furthermore, should not the new names be simple or at least readily comprehensible? Should they not aid visualization? And should they not somehow unveil the complex of conditions under which a given rock originated?

In pursuance of this belief, the renaming of rocks falling under A 1 and B 2 is considered from five points of view: (1) rock source of the sediment; (2) size and shape of grain; (3) degree of cementation; (4) mineral composition; (5) fossil content.

1. *Rock source.*—Seemingly, there is much satisfaction in speaking of aqueous and eolian sediments, perhaps even more in mentioning an anemopotamoclast. Nevertheless, such terms do not aid the sedimentary-rock student in the same way that peridotite or bostonite aids the igneous-rock student. True, one cannot assert that sands from gabbro rock sources will look different from sands from granite rock sources; of the requisite thin sections there are too few descriptions to tell. In the writer's own experience, nevertheless, Cambrian sands derived from the microcline granites of Wyoming do seem to have a characteristic appearance under the microscope. Would it not secure definiteness of description if sedimentary rocks, mainly, of course, sandstones, had prefixed to their colorless names such terms as granitogene, gabbrogene, quartzitogene?

2. *Size and shape of grain.*—Shape of grain should be an essential part of a microscopic description. The terms angular, near-angular, subrounded, rounded might constitute a useful series.

Size of grain is, under the microscope, capable of exact delimitation. The scale used in connection with igneous rocks is not, however, subdivided enough. Accordingly, the adoption of a modification of the New York City Aqueduct standard is advocated. The terms suggested chiefly, perhaps, apply to sandstones, somewhat to limestones, little to shales.

Sedimentary rock very coarse-grained	grains over 1 mm.
Sedimentary rock coarse-grained	grains between 0.5 and 1 mm.
Sedimentary rock medium-grained	grains between 0.25 and 0.5 mm.
Sedimentary rock fine-grained	grains between 0.1 and 0.25 mm.
Sedimentary rock very fine-grained	grains between 0.05 and 0.1 mm.
Sedimentary rock superfine-grained	grains below 0.05 mm.

By this scale, of course, arkoses, graywackes, conglomerates, breccias, even most grits would be very coarse-grained. It will be observed, however, that the terms in the table refer to measurements under the microscope and for sandstones, limestones, and

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shales only. For field use in connection with arkose, graywacke, conglomerate, breccia, and grit, other sizings for fine-grained, medium-grained, coarse-grained are advocated.

Fine-grained arkose (graywacke, etc.).....grains to $\frac{1}{8}$ in. in diameter
Medium-grained arkose (graywacke, etc.)....grains from $\frac{1}{8}$ to $\frac{1}{4}$ in. in diameter
Coarse-grained arkose (graywacke, etc.).....grains over $\frac{1}{4}$ in. in diameter

In most cases, particularly in conglomerates, maximum and minimum as well as average sizes should be noted.

Some term seems needed to denote a rock which is mainly an even-sized matrix, but contains a few pebbles over $\frac{1}{4}$ in. in diameter. Pebbled sandstone, pebbled limestone, pebbled shale are advanced.

3. *Degree of cementation.*—The microscope permits the abandonment of the field terms to denote hardness: soft, subsoft, hard, superhard. The following incomplete table is tentatively offered for criticism.

Rock Not Well Cemented (Primarily field terms)	Cemented; Grains Not Interlocked	Cemented; Grains Interlocked
Sandrock	Sandstone to quartzite sandstone	Orthoquartzite / Paraquartzite
Limerock	Limestone	Orthomarble / Paramarble
Magnesian limerock	Dolomite	Orthodolomite / Paradolomite
Clay	Shale	Slate
Arkose	Arkosite to quartzite arkose	Arkositite
Glauconite sandrock	Glauconitite (existent?)	Existent?
Ferrite sandrock	Ferrite	Existent?
Gravel	Conglomerate	Quartzite-conglomerate

Most of these terms are comprehensible at a glance. By orthoquartzite is meant rock cemented only through infiltration and pressure. By paraquartzite is meant quartzite mainly originating through contact metamorphism.

Doubtless it is illogical to remove quartzite, marble, and slate from the category of metamorphic rocks. However, quartzites, slates, and marbles are universally given a place in vertical sections and in geologic folios are described under sediments. Schists and gneisses are not so treated. Practical exigencies would seem to override Aristotelian "laws."

4. *Mineral composition.*—In the field, proportions between minerals cannot be determined. Under the microscope they can. The only true problems which arise concern the existence in given rocks of varying proportions of quartz and feldspar, of quartz and calcite, of quartz and glauconite, of calcite and siderite, of calcite and glauconite, of siderite and glauconite, or of various analogous but rarer combinations. At present, arenaceous limestone is used to denote a rock preponderantly calcareous and, may we say, one-fourth arenaceous. Calcareous sandstone is employed when such percentages are reversed. But in the writer's experience a number of rocks exhibit percentages of minerals close to 50:50. It is suggested that such terms as calarenite, sidarenite, glaucarenite would prove useful and not uneuphonious names for 50:50 combinations of calcite and quartz, siderite and quartz, glauconite and quartz. Limestone-glauconite, limestone-ferrite are examples of similarly compounded names for other mineral mixtures in rocks. Simple field names suggested on page 655 would thus be used only in emergencies.

The presence of glauconite involves a minor problem. Except when calcite is a cement, its presence in small percentage in a sandstone would hardly warrant the use of the name calcareous sandstone. Glauconite, however, throws some light upon the conditions of deposition. It is advocated that glauconitic as an adjective be employed even if the percentage in a sandstone or limestone be as low as 5 per cent.

5. *Fossil content.*—Fossiliferous sandstone, shale, and limestone are names already familiar. However, every geologist should recognize at sight the various invertebrate phyla and the main classes. And many geologists could thus characterize fossil-bearing rocks as predominantly graptolitic, coralline, vermicosic, pelmatozoic, bryozoan, brachiopodic, molluscan, trilobitic, etc. Coquina seems to be a term for pelecypodic limerock.

ILLUSTRATIVE DESCRIPTIONS OF SEDIMENTS

With some hesitation, the present discussion is closed with illustrative descriptions of hand specimens of Cambrian rocks and

of thin sections made therefrom. Each description, though brief, includes (1) locality, position in stratigraphic column, and description of field specimen; (2) texture, list of constituents, and relative proportion of more important minerals; (3) description of the chief mineral or minerals; (4) brief description of minor minerals; (5) name. Items (1), (2), (3), (5) are never omitted, and here each is given a separate paragraph; (4) is sometimes omitted. Terms logically connected are hyphenated, as fine-grained; glauconite-limestone; ferruginous-calcareous.

The descriptions are, as stated, purely illustrative. It may be added, however, that the writer has ventured partly to base upon these and other thin sections certain conclusions upon Middle Cambrian paleogeography rather at variance with the accepted account for Wyoming.

Wy 16: Taken in unnamed creek on south side of Duncom Mountain, $\frac{1}{8}$ mile east of Devil Canyon Road, 20 ft. above granite.

Description of hand specimen: Arkose, massive, gray-yellow to buff, weathering brownish-white to gray, with grayish-pink irregular lenses, cross-bedded; pebbles quartz and feldspar, usually about $\frac{1}{4}$ in., in finer but arkosic matrix; quartz angular to subrounded, iron-stained; feldspars pink angular cleavage fragments; traces of basic material?

Texture granular-fragmental. Constituents quartz, 80 per cent; microcline and a plagioclase near oligoclase, 15 per cent; small amounts of orthoclase, biotite, ilmenite, zircon, apatite, as accessories, and kaolin, sericite, leucoxene, muscovite, limonite as alteration products. Liquid and gas inclusions in quartz. Cement quartz and limonite.

Two marked groups of quartz grains. Larger average 0.4 to 0.5 mm. in diameter, smaller 0.06 to 0.08 mm. Larger grains subrounded to oval, smaller angular. Vein quartz suggested by wavy extinction.

Microcline fragments quadrangular, fresh; plagioclase same. Either rarely over 0.08 mm. Muscovite apparently not primary.

Classed: granitogene fine-grained arkose.

Wy 23: Taken at Middle Fork of Crazy Woman Creek,[1] 15 ft. above granite.

Description of hand specimen: Arkose, quartzitic, red-brown, massive, coarse, interbedded with finer-grained non-arkosic sandstones. Quartz grains rounded, uniform-sized, up to $\frac{1}{8}$ in. in diameter. Feldspars fresh cleavage fragments, about 33 per cent of rock, up to $\frac{1}{8}$ in. in diameter. General vitreous luster.

Texture granular-fragmental, secondary growth of quartz grains. Constituents quartz, 95 per cent; small amounts of biotite, limonite, apatite, zircon (?). Cement quartz and limonite.

One quartz fragment 3 mm., largest otherwise 0.15 mm.; 50 per cent of quartz 0.8 to 1 mm.; rounded and oval.

Classed: granitogene fine-grained arkosite.

Wy 27: Taken at Johnson Creek, 4 ft. above granite.

Description of hand specimen: Sandstone, massive, buff, with $\frac{1}{16}$ in. bands of chocolate-brown, doubtless iron stain along obscure bedding planes; contains rare pebbles of purplish shale and yellowish quartz, minimum $\frac{1}{8}$ in., maximum 1 in. In general medium-grained, friable, subvitreous luster.

Texture granular-fragmental. Constituents quartz, 60 to 80 per cent, dependent on amount of feldspar, now altered to sericite; small amounts of microcline, biotite, hornblende, plagioclase near oligoclase, zircon, apatite, magnetite, ilmenite (inclusion) as accessories, and kaolin and sericite as alteration products. Liquid and gas inclusions in quartz. Cement limonite, kaolin, sericite, possibly chalcedony.

Quartz vari-sized, largest grain 0.55 by 0.25 mm., no grains below 0.05 mm.; near-angular to subrounded, frequently oval. Feldspars suggest secondary growth, averaging 0.05 to 0.08 mm.

Classed: medium-grained pebbled sandstone.

Wy 50: Taken $\frac{1}{4}$ mi. from mouth of tributary, flowing westward from Hunt Mountain to South Beaver Creek, in float not far above granite; similar material in place, 30 ft. south and 10 ft. above granite.

[1] The belt of exposure is so narrow that this locality seems sufficiently identified.

Description of hand specimen: Arkose conglomerate, pebbles not ranging above $\frac{3}{8}$ in. Prevailing color where fresh dark-brown shot with gray, the pink of feldspar sharply contrasting; from dirty grays and whites of weathered surface pebbles stand out in relief. Fucoid markings on what may be bedding-planes 1 in. apart. Pebbles 90 per cent quartz, faintly brownish-green, rounded to near-angular, breaking with matrix; feldspars pink fresh cleavage fragments. Matrix 90 per cent of rock, sand, fine-grained, dull to earthy luster.

Texture granular-fragmental, large grains showing micrographic intergrowth. Constituents quartz 90 per cent; microcline, orthoclase, uncertain plagioclase 8 per cent; small amounts of biotite, apatite, zircon as accessories, and sericite, kaolin, limonite, and chlorite as alteration products. Liquid and gas inclusions in quartz. Cement a sericitic-kaolinic-limonitic "mess."

Quartz vari-sized, 1.5 by 0.8 mm. in larger grains, perhaps vein quartz, to judge by wavy extinction; average grains, 0.08 mm.; rounded to near-angular. Microcline fresh, 0.03 to 0.04 mm. Orthoclase same size, largely sericitized. Much organic material, seemingly chitinous.

Classed: ferruginous arkose-conglomerate.

Wy 93: Taken on Willow Creek at Burgess Ranger Station, 2 ft. above granite.

Description of hand specimen: Shale, thin-bedded, green when fresh, sparsely specked with glistening mica flakes and containing lenses of whitish-green sandstone, 1 in. long; on weathered surface bluish-black. Hard, arenaceous, fracturing irregularly, fresh surface of dull luster, bedding-planes subvitreous luster and slightly wavy.

Texture granular-fragmental, pilitic through alteration and with parallel arrangement of minerals, excluding quartz. Constituents chlorite, sericite, epidote, presumably alterations from biotite, muscovite, feldspar; small amounts of quartz, plagioclase, magnetite, zircon. Glauconite indeterminable. Cement a sericitic-chloritic felt.

Quartz rarely 0.06 mm., very angular. Plagioclase rare. Biotite bleached.

Classed: micaceous-arenaceous shale.

Wy 2: Same locality as *Wy 16*, 40 ft. above granite.

Description of hand specimen: Sandstone, thin-bedded, alternating and interleaved with fissile green shales; now banded green and white, subsoft, micaceous, now reddish-green, medium-grained, calcareous.

Texture granular-fragmental. Constituents quartz 90 per cent; glauconite 8 per cent; magnetite, ilmenite, calcite as accessories, limonite and leucoxene as alteration products. Cement calcite.

Quartz averages 0.05 mm., angular; rare vein quartz. Glauconite in aggregates (0.16 mm. diameter) oval to rounded, bordered and veined by limonite; no seeming relation to shell fragments.

Classed: glauconitic superfine-grained sandstone.

Wy 9: Same locality as *Wy 16*, 170 ft. above granite.

Descripton of hand specimen: Glauconite sand, massive, emerald green, crumbling, coarse-grained, subvitreous luster.

Texture granular-fragmental. Constituents glauconite 95 per cent; limonite as alteration product 5 per cent. Cement limonite. Various chitinous fragments and rods.

Glauconite aggregates as in *Wy 2*, but fresher.

Classed: glauconite sandrock.

Wy 25: Same locality as *Wy 27*, approximately 30 ft. above granite.

Description of hand specimen: Sandstone, massive, buff where fresh, weathering dark-red. Superhard, fine-grained, dull luster. Weathering exhibits buff nodules in relief.

Texture granular-fragmental. Constituents quartz 85 per cent; small amounts of biotite, muscovite, glauconite, magnetite, ilmenite, plagioclase, microcline, zircon, apatite as accessories, and leucoxene, kaolin, limonite, sericite, chlorite, epidote as alteration products. Liquid and gas inclusions in quartz. Cement quartz and limonite.

Quartz averages 0.2 mm., angular; fragments often elongate; one grain 0.6 by 0.35 mm; vein quartz rare. Plagioclase a mass

of sericite needles, microcline much fresher; average size for both, 0.05 mm. Biotite shredded. Muscovite largely secondary, but some long twisted primary fibers.

Classed: granitogene glauconitic-ferruginous fine-grained sandstone.

Wy 58: Taken at Turkey Creek, $\frac{1}{4}$ mi. south of Steamboat Point, 9 ft. above granite.

Description of hand specimen: Limestone, 1-in. lenses, reddish-brown, coarse-grained; occurring in shale, fissile, paper-thin, green with silky luster, trilobitic on bedding-planes (*Ptychoparia*), brachiopods rare.

Texture granular-fragmental. Constituents calcite 95 per cent; small amounts of quartz, magnetite, zircon, siderite as accessories. Cement calcite and a trifle limonite.

Calcite averages 0.75 mm.; often in rods and rectangular blocks, obviously fossil fragments, the remaining calcite due to solution and redeposition. Within shell fragments a finely comminuted mixture of quartz, calcite, siderite; limonite, probably from siderite, outlines fragment edges. Quartz 0.02 to 0.03 mm., angular.

Classed: coarse-grained brachiopodic limestone.

Wy 99: Taken at Deer Creek, 1 mi. northwest of Sheep Mountain, 100 ft. below the persistent sandstone described as *Wy 89*.

Description of hand specimen: Limestone, massive 1-in. bed between thick green shales; gray-blue, weathers dirty-brown, crossed by veins of calcite; hard, medium-grained, subvitreous luster, brachiopodic and trilobitic.

Texture granular-fragmental. Constituents calcite 90 per cent; small amounts of quartz, magnetite, glauconite, pyrite, zircon, ilmenite as accessories, and leucoxene as alteration product.

Calcite 0.35 mm., anhedral; at times within shell fragments and then comminuted; "rods" clearly from genal spines of trilobites, fragments 4 to 5 mm. long. Quartz mainly in shells, angular, seldom as much as 0.04 mm. Glauconite seemingly developed in shells. Much chitinous material.

Classed: medium-grained brachiopodic trilobitic glauconitic limestone.

Wy 105: Taken at Horse Creek No. 3, 1 mi. west of Sheep Mountain, 125 ft. above granite and at much the same horizon as *Wy 99*.

Description of hand specimen: Limestone, massive, light-green and specked with hard black grains, weathering dirty brown-red. Hard, fine-grained, subvitreous luster, fractures conchoidally.

Texture granular-fragmental. Constituents calcite 60 per cent; glauconite 30 per cent; quartz 10 per cent. Magnetite and zircon as accessories, and limonite as alteration product.

Calcite 0.15 mm., probably due to recrystallization.

Calcite in shell fragments as in *Wy 99*. Quartz grains surprisingly large, average 0.1 mm. and up to 0.5 mm.; very angular. Glauconite in large aggregates, even 2 by 8 mm.; some curved, as if by replacement of whole fossils; indifferently near to or remote from magnetite; fresh. Limonite mainly from magnetite.

Classed: fine-grained brachiopodic trilobitic glauconite-limestone.

Wy 89: Taken from massive bench on south side of Bald Mountain.

Description of hand specimen: Sandstone, massive, pinkish buff, slightly splotched with brown, weathering dull grayish-white; subsoft, fine- to medium-grained, traces of shale streaks, earthy to subvitreous luster, brown splotches interpreted as oxidation of trilobite shields. Cross-bedded? Most persistent bed in the Cambrian below the flat pebble.

Texture granular-fragmented. Constituents quartz 95 per cent; small amounts of biotite, magnetite, ilmenite, plagioclase, glauconite as accessories, and leucoxene and limonite as alteration products. Cement quartz and calcite.

Quartz averages 0.15 mm.; largest grain 0.3 by 0.15 mm.; angular, sufficiently cemented to suggest quartzite; few indications of secondary growth. Grains limonite-rimmed. Biotite much shredded. Chitinous rods.

Classed: fine-grained quartzite-sandstone.

Wy 63: Same locality as *Wy 58*, 150 ft. above granite.

Description of hand specimen: Limestone, massive, gray-green, weathering reddish-brown to gray. Subsoft, medium-grained, argillaceous, arenaceous, glauconitic, ferruginous.

Texture granular-fragmental. Constituents calcite 50 per cent; quartz $33\frac{1}{3}$ per cent; siderite 10 per cent; small amounts of magnetite, ilmenite, zircon, muscovite, glauconite as accessories, and limonite as alteration product.

Calcite 0.2 mm., giving evidence of recrystallization; also as rods. Glauconite aggregates about 0.5 mm., much replaced by limonite. Limonite also edges siderite rhombs. Quartz 0.04 mm., near-angular to subrounded.

Classed: arenaceous trilobitic medium-grained glauconite-limestone.

Wy 13: Same locality as *Wy 16*, 260 ft. above granite.

Description of hand specimen: Limestone, thin-bedded, blue-gray, subsoft but brittle, the 1-in. layers separated by micaceous shale; subvitreous luster, black-specked, seemingly unfossiliferous.

Texture granular-fragmental. Constituents calcite 50 per cent; quartz 25 per cent; glauconite 20 per cent; small amounts of ilmenite, zircon, apatite as accessories. Liquid and gas inclusions in quartz. Cement calcite.

Quartz 0.1 mm., angular. Calcite grains 0.5 mm.; main occurrence as rods.

Classed: arenaceous trilobitic medium-grained glauconite-limestone.

Wy 87: Same locality as *Wy 89*, 4 ft. above that horizon.

Description of hand specimen: Sandstone, massive, gray-green with irregular-bedded effect due to light-colored stretches between dark-brown bands, with parallel orientation of *Dicellomus* shells; soft, coarse-grained, calcareous, particularly toward top, glauconitic, dull to subvitreous luster. Cross-bedded.

Texture granular-fragmental. Constituents quartz 80 per cent; glauconite 10 per cent; calcite 5 per cent; small amounts of biotite, muscovite (?), apatite as accessories. Cement calcite. Liquid and gas inclusions in quartz.

Quartz 0.2 to 0.5 mm., subrounded to oval, at times subhexagonal. Glauconite seldom related to shell interiors, not even in an admirable cross-section with quartz fragments in shell and cemented by calcite and limonite.

Classed: glauconitic medium-grained sandstone.

Wy 84: Taken at Cambrian Creek, tributary to East Fork of Little Bighorn River, long. 10° 45′ W., lat. 44° 50′ N., 34 ft. below the flat-pebble conglomerate.

Description of hand specimen: Limestone, massive, gray-green, weathering gray to reddish brown, subsoft, coarse-grained, arenaceous, glauconitic, subvitreous luster, with calcite veins and 1-in. crystals; breaks in smooth angular blocks; presents corrugated surface where calcite has dissolved on weathering.

Texture granular-fragmental. Constituents quartz 47 per cent; calcite 47 per cent; small amount of glauconite as accessory, and limonite as alteration product. Cement calcite.

Quartz averaging 0.3 mm., largest grain 0.5 by 1.8 mm.; subrounded; grains broken and healed by calcite; slight traces of secondary growth; small grains seemingly fragments of larger ones cemented. Calcite shows recrystallization. Glauconite aggregates about 0.1 mm., rounded. Bryozoan-like fragments.

Classed: glauconitic trilobitic medium-grained calarenite.

Wy 66: Taken on south side Tongue River, directly opposite mouth of Sheep Creek, 60 ft. below the Cambrian-Ordovician contact.

Description of hand specimen: Limestone, $\frac{1}{16}$- to 1-in. beds, greenish-white to buff, hard, fine-grained, argillaceous, arenaceous, subvitreous luster, slightly ripple-marked, raindrop-pitted (?).

Texture granular-fragmental. Constituents siderite 30 per cent; calcite 30 per cent; quartz 30 per cent; glauconite 5 per cent; a little apatite, ilmenite, muscovite, magnetite, and plagioclase; muscovite and plagioclase very rare; a little limonite as alteration product.

Calcite averages 0.1 mm., larger grains 0.2 mm. Quartz 0.05 mm., near-angular to subrounded; inclusions of hematite scales (?). No fossils.

Classed: glauconitic-arenaceous medium-grained siderocalcite.

Wy 72: Taken on East Fork of Little Bighorn River, 2 mi. northeast of Little Bald Mountain, at base of Ordovician "Bighorn dolomite."

Description of hand specimen: Limestone, 4- to 6-in. beds, gray-green, weathering light buff with yellow stains, hard, fine-grained, slightly dolomitic, argillaceous, dull luster, lower beds much jointed, causing weathering in subquadrate slabs; flat-spired gastropods abundant.

Texture granular-fragmental. Constituents calcite 99 per cent; a little accessory glauconite, limonite as alteration product. Cement calcite.

Calcite grains often recrystallized, largest 0.3 mm. and apparently cavity-filling.

Classed: gastropodic medium-grained limestone; traces of glauconite.

Wy 69: Same locality as *Wy 2*, 2 ft. below Cambrian-Ordovician-contact.

Description of hand specimen: Conglomerate, massive, greenish-gray; pebbles limestone, distinguishable with difficulty on weathered surface, greenish, subsoft, fine-grained, glauconitic, flattened, elongated, length $\frac{1}{4}$ in. to 2 in., often loose ochreous earth, lining cavities, when fresh breaking with matrix, and usually aligned in parallel planes, constituting 50 per cent of rock; matrix limestone, greenish, fine-grained, dull luster. (This is the famous flat-pebble conglomerate of Dakota and Wyoming.)

Texture conglomeratic. Constituents calcite 90 per cent; small amounts of glauconite, quartz, pyrite, magnetite as accessories, and hematite and limonite as alteration products. Cement calcite.

Calcite either as pebbles, merely fragmentary in slide, or as interlocked crystals in matrix. Pebbles characterized by calcite, criss-crossed and specked with glauconite (percentage from 25 to $33\frac{1}{3}$), and interlocked with quartz grains below 0.01 mm. diameter. Quartz very rare in matrix. Pyrite altering to hematite and limonite.

Classed: glauconitic flat-pebble limestone-conglomerate.

Wy 24: Same locality as *Wy 23*, 20 ft. below Cambrian-Ordovician contact.

Description of hand specimen: Seemingly *sandstone* (and so described by one observer), massive, pink, weathering fainter pink.

Superhard, fine-grained, argillaceous, and seemingly *slightly calcareous*, subvitreous luster.

Texture granular. Constituents dolomite 90 per cent; quartz 5 per cent; small amounts of magnetite, glauconite, ilmenite as accessories, and limonite as alteration product. Cement dolomite and limonite.

Dolomite in rhombs, inclusions of limonite; averages 0.07 mm. Quartz rarely over 0.02 mm., very angular. Glauconite altering to limonite, latter also between dolomite crystals.

Classed: glauconitic superfine-grained dolomite.

Reviews

The Cost of Mining. By JAMES R. FINLAY. Third edition (entirely revised, enlarged, and reset). McGraw-Hill Book Co., 1920.

The new edition of this standard work on mining costs in addition to amplifying and bringing up to date the data on mining costs found in the earlier editions, contains a considerable amount of material of broader economic interest relating to mineral resources. Chapter I, for example, discusses mineral wealth as a source of national power, chapter III treats of the nature and use of capital.

The cost of mining data is presented seriatim by mineral commodities and covers coal, iron, copper, lead, silver-lead, zinc, gold, and silver. The chapter dealing with each of these is commonly prefaced by some general discussion and by statistics of production. Cost data for iron-mining relate only to the Lake Superior region.

In the chapters devoted to copper occur such paragraph headings as "Geologic Unconformities at Jerome," "Characteristics of Belt Rocks," "Theories of Formation of Jerome Deposits," etc.; the book is therefore somewhat broader in scope than its title would suggest. The book commends itself not only to the engineer but to the economist, geologist, or geographer concerned in the rôle of mineral resources in the industrial life of the United States.

E. S. BASTIN

Extracts from "The Mining Handbook," Geological Survey of Western Australia, Memoir No. 1, 1919. A series of advance separates of chapters from the foregoing *Handbook.*

This mining handbook is a worthy attempt to furnish to those interested in mining in Western Australia a large amount of varied information likely to prove of service to them in the exploitation of mineral deposits. The handbook includes chapters on the relations of physiography and of petrology to the exploitation of mineral deposits, chapters expounding the mining regulations and explaining various methods of governmental assistance to prospecting and mining. Then follow chapters dealing with the major base metals, with the various

steel-alloying metals, with the minor metals, and, finally, with coal and a few non-metallic mineral resources.

The chapter on physiography in its relation to prospecting and mining is mainly a discussion of the influence of topography on the discovery and development of ore bodies and, reciprocally, the influence of ore bodies on topography.

The chapter on minerals of economic value lists the composition and the principal physical properties of economic minerals and cites their main utilizations.

The chapter on petrology and its application in industry is an exposition of petrology in its simplest form, defining the principal rock-forming mineral and the principal groups of igneous, sedimentary, and metamorphic rocks and expounding the application of petrology in geologic surveying, in the study of ore deposits, in engineering, architecture, and agriculture.

The chapter on the relation of the law to prospecting and mining covers the legal restrictions governing the location and development of mineral deposits in Western Australia. Three points of contrast between the Western Australian mining laws and those of the United States are noteworthy. In the United States, discovery must precede the staking out of mining claims and ground cannot be validly held until there has been an actual discovery of mineral. In Western Australia ground can be marked out and held, even though no minerals have been discovered. In the United States title in fee simple to a mining claim is acquired by patent, subject to extra-lateral rights of adjoining claim-owners. In Western Australia the crown does not part with the title to the land. Leasehold is the rule, coupled with labor conditions.

In Western Australia the principle of extra-lateral rights, which has resulted in so much troublesome litigation in the United States, does not apply but the holder of a mining lease is only entitled to such portions of the lode or lodes as occur within the boundaries of his lease extended vertically downward from the surface.

An interesting feature of the Western Australian mining law is the provision for a reward of up to one thousand pounds, offered for the discovery of payable gold at a place distant more than two miles from any place where payable gold has up to then been discovered. Several other forms of governmental assistance to mining include advances for the purpose of pioneer mining and prospecting, the establishment and subsidizing of plants for ore treatment, assistance for drilling, including the purchase or hire of drilling plants, the advancement of money for

drainage, shaft sinking, and for development of transportation facilities to assist mining operations. A separate chapter, entitled "Assistance to Prospecting and Mining," explains these various forms of governmental assistance in detail and also lists geographically and by minerals all available government reports and maps covering mining districts. Another chapter is a glossary of common terms in mining and geology.

Among the major metals, iron ores though widely distributed in Western Australia have as yet been developed only on a small scale for the production of flux for copper and lead smelting and no detailed geologic surveys have been made of any of the iron deposits. Copper deposits, though widely distributed, have been developed only to a minor degree. The production of lead ores has been small.

Among the steel hardening metals, the production of manganese, tungsten, and molybdenum has been so small as to be essentially negligible. Among the rare metals, there has been little or no development.

The small tin production has come mainly from alluvial deposits, but in the Wodgina tin field, tin and tantalum occur in pegmatite dikes which, together with granite, intrude metamorphic sedimentary rocks. The chief constituents of these pegmatitic dikes are albite and quartz, with occasionally scaly lepidolite and tourmaline; in addition, orthoclase, mangano-tantalite, and tin occur in varying quantities, as well as some of the rare radioactive minerals. In the vicinity of and along the margin of many of the pegmatite dikes are bands and bunches of tourmaline, sometimes to such an extent as to make up fully one-third of the entire rock. One of the most conspicuous of the pegmatite veins, about half a mile in length and 30 feet in width, has proved to be sufficiently rich in tin and tantalum to be worked.

The tin ore, cassiterite, is concentrated along certain lines in the pegmatites and does not appear to be generally disseminated in minute quantities throughout its mass. The tin occurs in all shapes, from minute grains up to pieces weighing as much as 100 pounds.

The coal deposits of Western Australia range in age from Carboniferous, through Permo-Carboniferous to Mesozoic, Tertiary, and post-Tertiary. The only deposits which have been extensively mined are those of the Collie field of Permo-Carboniferous age. In this field the total thickness of the coal seams is about 137 feet. The coals are semi-bituminous, non-coking coals which are dirty to handle and deficient in volatile materials. It is interesting to note that the coals appear to be mainly of drift origin and to have been deposited by current action on an extensive basin or river valley. The banded appearance of most

of the coals and their relatively high percentage of ash is probably a result from this mode of origin as is also the absence of fire clays beneath them. The available reserves of the field are estimated at three and one-half billion tons.

E. S. BASTIN

Summary Report, Canadian Geological Survey. Ottawa, 1919. *Part C. Alberta-Saskatchewan Region.* Pp. 52.

1. "Cretaceous, Lower Smoky River, Alberta." By F. H. MCLEARN.
2. "Geology of the Swan Hills in Lesser Slave Lake District, Alberta." By JOHN A. ALLEN.
3. "Northern Part of Crowsnest Coal Field, Alberta." By BRUCE ROSE.
4. "Gasoline in Natural Gas. Experiments on Alberta Gas." By D. B. DOWLING.
5. "Surface Deposits of Southeastern Saskatchewan." By J. STANSFIELD.

The annual *Summary Report of the Canadian Geological Survey* for 1917 and since is issued in parts and each part is designated by a letter of the alphabet. Before 1917 the whole annual *Summary* was bound in one large volume.

1. The Cretaceous begins with the Lower Cretaceous and extends into the Montana group of the Upper. Marine and non-marine formations alternate and the total thickness represented is about 4,470 ft. The Dakota sandstone cannot be recognized in its normal subaerial development. The beds dip to the south from 12 to 60 ft. per mile and represent the north limb of a very broad, shallow syncline. The structure is not favorable for oil.

2. The Swan Hills lie south of Lesser Slave Lake, have a maximum elevation of 4,320 ft. above sea-level, and represent remnants of a once more extensive, maturely dissected upland. The Cretaceous is represented by the Montana group. The basal member is marine, and the upper two members, the Sawbridge and Edmonton, are of fresh-water origin. The early Tertiary is represented by the Paskapoo formation but there is no marked unconformity between the Upper Cretaceous and the Tertiary.

3. Formations ranging from Devono-Carboniferous to Upper Cretaceous, probably Tertiary, in age, are described. Coal seams of

economic importance are found only in the Kootenay, and a large reserve of bituminous coal occurs within the Rocky Mountains.

4. This is a description of the apparatus and the results of a number of experiments carried on at various gas wells. At the pressures under which the tests were made the amount of gasoline in the Alberta gases per 1,000 cu. ft. varied from 0.1 pints to 3.7 pints.

5. This area is covered with glacial drift, averaging from 40 to 70 ft. in thickness. Two main terminal moraines cross the area but ground moraine covers most of the area. The residual alkali material formed in the dried-up sloughs contains only a very small per cent of potash, and is of no economic importance. The waters from the drift are hard and contain calcium and magnesium carbonates and sulphates while the waters from wells reaching the Tertiary strata are soft and contain considerable sodium chloride.

Part D. Manitoba Region. Pp. 19.

1. "Athapapuskow Lake District, Manitoba." By E. L. BRUCE.
2. "The District Lying between Reed Lake and Elbow Lake, Manitoba." By E. L. BRUCE.
3. "Reed-File Lakes Area, Manitoba." By F. J. Alcock.
4. "Wekusko Lake Area, Manitoba." By F. J. Alcock.
5. "Superficial Deposits and Soils of Winnepegosis Area, Manitoba." By W. A. JOHNSTON.
6. "Gold-Quartz Veins and Scheelite Deposits of Southeastern Manitoba." By E. L. BRUCE.

1. Chalcopyrite was discovered along joint or fracture zones in fine-grained, massive greenstone. Some distance from these occurrences the greenstone is intruded by granite and these deposits are directly related to these intrusions. With the present conditions of transportation mining conditions are not favorable for this area.

2. The geology of this area is much simpler than that of other nearby areas in northern Manitoba as the pre-Cambrian is represented by the Amisk series of greenstones and derived schists, and intrusive granites. The younger pre-Cambrian formations are absent, and since the crest of a large anticline crosses this area these younger formations have probably been removed by erosion from the crest of this anticline. Ordovician dolomites and Glacial and Recent deposits are noted. No

economic deposits have yet been discovered and on the whole conditions for the formation of ore deposits have not been as favorable as in nearby areas.

3. The pre-Cambrian rocks of this area are divided into an igneous complex consisting of altered volcanic and intrusive rocks, a sedimentary complex of granite-gneiss and staurolite-schist, and batholithic intrusives. Ordovician dolomites occur and Pleistocene and Recent deposits are abundant.

4. The geology of this area is very similiar to that of the Reed-File lakes area. A number of productive gold-bearing quartz veins occur near the borders of the granite masses.

5. Because of the practical exhaustion of homestead prairie land in easily accessible areas, a map of an area of about 1,500 sq. mi. around Lake Winnipegosis was prepared. This map will show the character of the soil and forests and will also indicate the land that can be readily cleared.

6. The gold-quartz veins in the pre-Cambrian rocks of southeastern Manitoba were sampled and assayed for both gold and platinum. Most of the assays showed a very small amount of gold present but in no case was platinum detected. In a fine-grained, massive, roughly sheeted, hornblendic rock scheelite occurs in small vuggy lenses not in all cases parallel to the sheeting. The returns from a shipment of the ore to the Ore Dressing Laboratory, Ottawa, were not encouraging.

Part F. Maritime Province Region. Pp. 36, figs. 3.

1. "Investigations in Western Nova Scotia." By E. R. FARIBAULT.
2. "Investigations in Western Nova Scotia and New Brunswick." By ALBERT O. HAYES.
3. "Peat Investigations." By A. ANREP.

1. A description of a number of small manganese deposits in Nova Scotia and notes on the occurrence of platinum in the scheelite and gold veins of the gold-bearing series.

2. The drift over the Carboniferous rocks of the Sydney coal basin contains bowlders of rocks which outcrop to the south of the basin and this with the general direction of glacial striae proves that the direction of ice movement in this part of Cape Breton Island was northward. This report is almost entirely economic and gives many details concerning the structure and extent of a number of coal horizons. The New

Ross, Lunenburg County, manganese deposits are described as occurring along a fissure in granite. Calcite and manganese oxide was deposited in this fissure and later movements broke up this vein and formed a frault breccia. Secondary enrichment from surface waters has concentrated the manganese oxide into bodies of workable size and high-grade ore.

3. A few preliminary results are given of investigations of peat bogs near St. John and Moncton, New Brunswick.

Part G. The Platinum Situation in Canada, 1918. By J. J. O'NEILL. Pp. 19, map.

The chief platinum-producing areas in Canada are in Ontario, British Columbia, and Yukon. In the nickel-copper ores of Sudbury, Ontario, platinum occurs as sperrylite, the platinum arsenide. In British Columbia platinum is found both in the solid rocks and the gravels. In the solid rocks three distinct types of deposits are recognized—first, in association with chromite in peridotite-pyroxenite rocks; second, in association with chalcopyrite deposits; third, in shear zones in typical granite. In the gravels of Yukon platinum is widely distributed but not in large enough quantities to be profitably exploited for this metal alone.

Canada appears to have possibilities of becoming one of the great producers of platinum. In 1918 only one hundred ounces of platinum were recovered, but probably more than 50,000 ounces of the platinum metals were contained in ores mined in Canada, but not recovered.

J. F. W.

The Silurian Geology and Faunas of Ontario Peninsula, and Manitoulin and Adjacent Islands. By M. Y. WILLIAMS. Canadian Geological Survey, Ottawa, Memoir 111, 1919. Pp. 195, appendices III, pls. XXXIV, figs. 6, maps 2.

In this memoir the author gives his conclusions, based on five seasons of detailed field work, on the general Silurian problems of southwestern Ontario. Detailed sections, descriptions, notes on origin and correlation, and complete fossil lists for the various members of the Silurian system are given. Nine diagrams are given to illustrate the conditions of sedimentation during various stages of the Silurian period. Nine new species of brachiopods and one new variety are described. The three appendices contain descriptions of a new species of brachiopod

by Foerste, a new species of crinoid by Springer, and two new species of corals by Chadwick.

The important physiographic feature of the area is the Niagara escarpment which is formed by the outcropping edge of the Niagara dolomite.

The Silurian formations classified on the basis of lithology fall into the following three groups in ascending order: (1) Alternating sandstones, shales, and limestones represented by the Medina-Cataract, Clinton, and Rochester formations and indicating changing conditions of land in respect to the sea. (2) Massive dolomites represented by the Lockport and Guelph formations and suggestive of widespread seas of moderate depth. (3) Saline sediments containing lenses of salt, gypsum, and impure clastic dolomites represented by the Cayugan group which were formed in shallow, practically isolated interior water basins.

The disconformity between the top of the Ordovician represented by the Richmond and Queenston shale, and the base of the Silurian represented by the Whirlpool sandstone is distinct. The Bass Island group of the west and the Akron dolomite of the east are put at the top of the Silurian and the disconformity between these formations and the basal Devonian is also well marked at a number of localities. Breaks in sedimentation occur at the base of the Lockport and Salina.

Chapter vi contains notes on the salt, gypsum, petroleum, natural gas, and other materials of economic importance found in the area.

The report is well illustrated and is a careful, detailed, and concise statement of the Silurian geology of southwestern Ontario.

J. F. W.

The Geography of Maryland. By WILLIAM BULLOCK CLARKE. *The Surface and Underground Water Resources of Maryland, Including Delaware and the District of Columbia.* By WM. BULLOCK CLARKE, E.B. MATTHEWS, and E. W. BERRY. Maryland Geological Survey, Vol. X, 1918. Pp. 553, figs. 96.

Part I is a brief discussion of the geology and physiography, including the Coastal Plain, Piedmont Plateau, and the Appalachian physiographic provinces, climate, flora and fauna, and the natural resources of the state. Among the chief resources may be mentioned coal, clays, building and decorative stones, limestone products, agriculture, and timber. A number of suggestions for physiographic and geologic excursions within the state are included.

Part II is a more detailed discussion of the geology and physiography of the region. The geology is dealt with by physiographic provinces and includes sedimentary, igneous, and metamorphic areas, and, stratigraphically, rocks from pre-Cambrian to Recent. The discussion of the underground water resources, which forms the greater part of the paper, includes an explanation of the general principles involved and local detailed descriptions of the resources by counties. There are appended to the report eleven tables of statistics of various sorts.

A. C. McF.

William Smith, His Maps and Memoirs. By T. SHEPARD, M.Sc., F.G.S. Proceedings of the Yorkshire Geological Society, N. S., Vol. XIX, Part III. Pp. 178.

William Smith was one of the pioneer English geologists in stratigraphic and areal work. The report consists of descriptions of his various maps and writings, the first produced in 1799 and the last in 1827. It includes many reproductions of the original diagrams and charts.

A. C. McF.

Upper Cretaceous of Maryland, Systematic Report. Maryland Geological Survey, 1916. Pp. 1022, pls. 7 (general), 90 (paleontological).

I. The Upper Cretaceous Deposits of Maryland," by W. BULLOCK CLARKE.—Under this heading is included a discussion of the general geology of the Coastal Plain region of the state, to which the Cretaceous deposits are limited, including the physiography, stratigraphy, structure, and conditions of sedimentation. A bibliography and table of distribution of the fauna and flora are also given.

II. "Petrography and Genesis of the Sediments of the Upper Cretaceous of Maryland," by MARCUS I. GOLDMAN. Based upon petrographic and field evidence.—The author finds three types of sediment present, (1) delta type, (2) lagoon type, and (3) open-water glauconitic type. A brief discussion of the origin of glauconite and the methods of petrographic examination is given.

III. "The Upper Cretaceous Floras of the World," by E. W. BERRY. —No attempt at detailed correlations of these widely scattered floras is made. A discussion of the place of origin and subsequent migrations of the great dicotyledonous flora, which makes its sudden and dominating

appearance in the Upper Cretaceous, is given. The flora shows great modernization compared with the Lower Mesozoic horizons. Extensive floral lists are given.

IV. "Correlation of the Upper Cretaceous Formations," by W. BULLOCK CLARKE, E. W. BERRY, and JULIA A. GARDNER.—Complete accordance between the faunal and floral evidence seems to be lacking. The problems involved are discussed in detail.

V. "The Systematic Paleontology of the Upper Cretaceous Deposits of Maryland," by R. S. BASSLER, E. W. BERRY, W. B. CLARKE, JULIA A. GARDNER, H. A. PILSBURY, and L. W. STEPHENSON.—Some 325 species and varieties are described of which approximately one-fifth are fossil plants. The majority of these are figured. The volume contains ninety plates of excellent figures. The report is of importance to the stratigraphic and paleontologic world.

A. C. McF.

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